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THE EFFECTS OF TEMPERATURE ON PHOSPHORESCENCE AND FLUORESCENCE.[1]

BY EDWARD L. NICHOLS.

(*Read April 22, 1910.*)

Fluorescence and phosphorescence are closely connected phenomena, the precise relation of which is not completely settled. In a general way we may say that the emission of light by a body under any one of the numerous stimuli which produce luminescence when observed during excitation is termed fluorescence; the after glow is phosphorescence. According to the quite generally accepted view, first expressed by Wiedemann and Schmidt[2] and since developed by Merritt[3] and in somewhat different form by Lenard[4] and others, luminescence is a phenomenon of dissociation in which negative ions or in the language of Lenard "electrons" are separated from the molecules by the action of light, cathode rays, X-rays, the radiation from radioactive materials, etc. These are supposed to return later to the aggregation from which they have been torn loose or to some other molecule and to produce by their collision the vibrations which are the source of the emitted light.

[1] The apparatus used in the experiments described in this paper was purchased in part under a grant from the Carnegie Institution.

[2] Wiedemann and Schmidt, *Annalen der Physik*, LVI., 1895, p. 177.

[3] Nichols and Merritt, *Physical Review*, XXVII., 1908, p. 368.

[4] Lenard, *Annalen der Physik*, XXXI., 1910, p. 1.

The formation of these free ions is a gradual process; measured in terms of the time of vibration of light, indeed, it is almost infinitely slow. If the fluorescence of a body subjected to moderate illumination be measured from second to second it will be found to increase in brightness, first rapidly, then, more and more slowly; approaching a maximum in some cases only after several minutes.

From such observations a sort of saturation curve may be plotted. In Fig. 1, which is from measurements by Professor Merritt and the present writer,[5] curve *A* is such a saturation curve

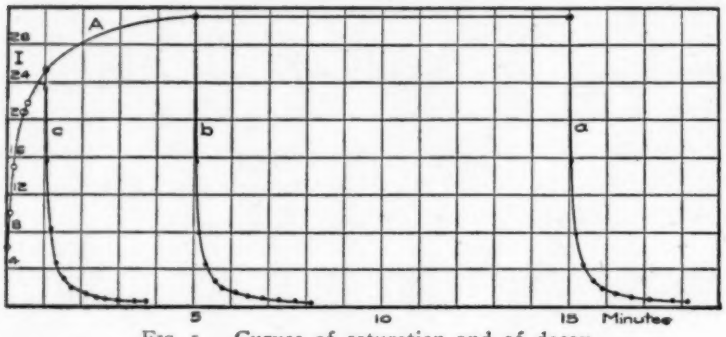

FIG. 1. Curves of saturation and of decay.

obtained by observing the increase in the brightness of fluorescence of a specimen of Sidot blende during an interval of fifteen minutes. Immediately upon the cessation of excitation the light from the fluorescent body begins to decrease; first rapidly, then more and more slowly and this phase of the phenomenon which may likewise be expressed by a curve, called the "curve of decay" is called phosphorescence. Curves *a*, *b* and *c* in Fig. 1 are the curves of decay of the phosphorescence of this specimen of Sidot blende when excitations is ended after 15 min., 5 min., and 1 min. respectively. The law of decay is always the same although the length of time required for the afterglow to become so feeble as to be invisible may vary from many hours[6] to an immeasurably small fraction of a second.

[5] Nichols and Merritt, *Physical Review*, Vol. XXIII., p. 46.

[6] Surfaces coated with the ordinary phosphorescent zinc sulphide or Balmain's Paint if exposed to sunlight and taken into a dark room have been know to continue to glow for months with sufficient intensity to fog photographic plates.

In the case of fluorescent liquids it was found by one of my former pupils, Dr. Waggoner,[7] that even with a special form of phosphoroscope, by means of which observation less than a thousandth of a second after the cessation of intense illumination were possible, no phosphorescence could be detected. It should be remembered, however, that 1/10,000 or even 1/1,000,000 of a second is a very long time measured in terms of the frequency of light, since the particles of a phosphorescent body emitting green light would oscillate some 500,000,000 times in a millionth of a second. We are not in position therefore to say that fluorescent liquids, in none of which phosphorescence has been observed, differ from phosphorescent bodies save in the rapidity with which the light decays.

By the use of this instrument Dr. Waggoner was likewise able to trace the phosphorescence of various compounds back to its very source at the cessation of excitation and to show how in the cases which he studied fluorescence merged into phosphorescence without discontinuity and the quality, or distribution of wave-lengths in any single band in the spectrum remained unchanged during the first few thousandths of a second. Professor Merritt and the present writer[8] had previously shown that in the case of a substance of slow decay (Sidot blende) the phosphorescence spectrum is identical, so far as the single band under observation was concerned, with the fluorescence spectrum and that "if any change occurs in the form of the phosphorescence spectrum during decadence, this change is extremely small."

According to this view the relation of phosphorescence to fluorescence would seem a very simple one but more detailed study develops complications such that the complete theory of the subject is as yet far from being perfected. Some of these complications are brought out particularly when we subject fluorescent or phosphorescent substances to change of temperature and it is with some of the phenomena accompanying such changes that I propose to deal in the present paper.

[7] Waggoner, *Physical Review*, Vol. XXVII., p. 209, 1908.
[8] Nichols and Merritt, *Physical Review*, Vol. XXI., p. 257, 1905.

When a body capable of phosphorescence is either heated or cooled and then exposed to light the intensity of its fluorescence is found to vary as are also the intensity and duration of its phosphorescence. Mere observations with the unaided eye suffice to show the following:

1. Very great changes occur in the rate of decay as the result of either cooling or heating.

2. The color of phosphorescence frequently differs at different temperatures.

3. The color of phosphorescence may be seen to vary markedly during decay, one tint gradually merging into another.

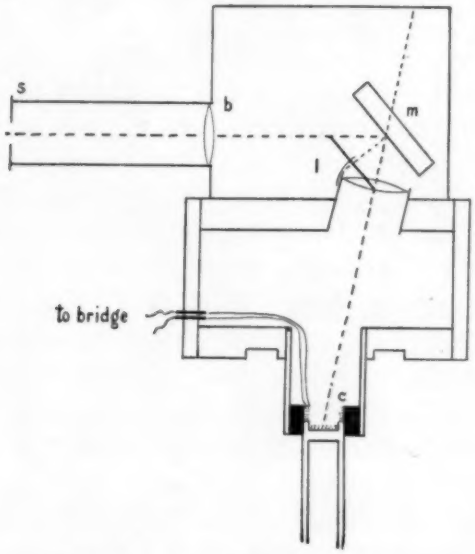

FIG. 2. Apparatus for cooling.

4. Fluorescence of one color is often followed by phosphorescence of another. W. S. Andrews,[9] for example, has noted the following in the case of artificial phosphorescent substances.

Compounds containing.	Fluorescence.	Phosphorescence.
(*a*) Zinc and manganese.	light pink	deep red
(*b*) Cadmium, manganese and sodium.	light pink	orange-yellow
(*c*) Cadmium and manganese.	yellow	light green

[9] Andrews, W. S., *Science*, Vol. XIX., p. 435, 1904.

To determine more exactly the effects of temperature on the duration of phosphorescence the following experiments, in which Mr. J. F. Putnam assisted me, were made. Several sulphides of known composition of the sort prepared by the method of Lenard and Klatt, a number of which are now on the market, were cooled by means of liquid air. The form of apparatus used is shown in Fig. 2.

The source of light was a flaming arc between carbons which were filled with salts yielding an ultra-violet spectrum of great intensity and unusual range. These carbons are known commercially as the "brilliant white." They gave an arc which under the conditions of our experiments excited the substances under observation to complete saturation in about six seconds.

The lamp was of the vertical carbon type with a large upper carbon, cored but not impregnated, and a smaller impregnated carbon below. The direction of the current was such as to make the latter the positive terminal. Such a lamp burns several minutes without feeding with an arc from one to two centimeters in length and of sufficient steadiness for the purpose in question.

A condensing lens of quartz 20 cm. focal length and 5 cm. diameter threw an image of the arc upon the wide horizontal slit *s*, the edges of which excluded light from both carbon tips. The light after passing the slit was rendered parallel by the quartz lens *l'* and fell upon a plane mirror *m* of speculum metal by which the beam was reflected obliquely downwards at an angle of about 70° through the similar lens *l''* which caused an image of the slit upon the substance to be observed. The substance in a thin layer of powder was contained in a shallow capsule at the top of a bronze tube about 20 cm. long. When in position the top of this tube was surrounded by a massive collar of copper which in turn was supported by a tube of hard fiber which afforded excellent thermal insulation. The whole was boxed in to prevent the gathering of frost. Observations of the phosphorescent substance were made through a horizontal tube inserted in the side of the box above the capsule and having a rectangular prism *p* at the inner end, as shown in Fig. 3.

To cool the phosphorescent compound the lower end of the bronze tube was submerged in a cylindrical Dewar flask containing liquid air and by the vertical adjustment of this tube any temperature from that of the room to about —185° could be reached and

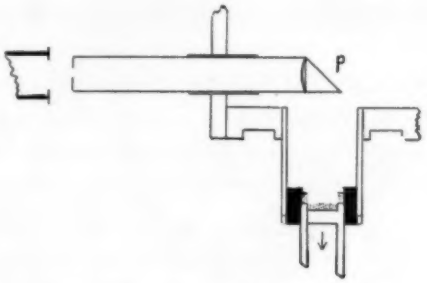

FIG. 3 Device for observing the cooled substance.

maintained. The temperatures were measured by noting the electrical resistance of a previously calibrated coil of fine copper wire *C* (Fig. 2) imbedded in the copper cylinder and immediately surrounding and in contact with the capsule. A shutter, the opening

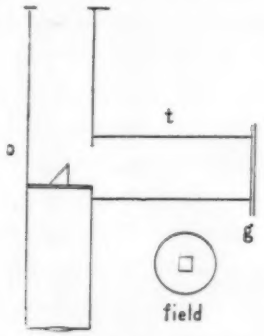

FIG. 4. The photometer.

and closing of which was automatically recorded by a chronograph, was used in making exposures to excitation.

For the determination of the curves of decay a specially designed photometer was used. This consisted of a slight tube *O*, Fig. 4, mounted horizontally in front of and coaxially with the

observing tube in the side of the box already described. Within this sight tube and in the focus of the eyepiece e a disk of thin plane glass was mounted in the middle of which was fastened, with Canada balsam, a very small rectangular prism. Opposite this a a side tube t was inserted, the outer end of which was covered with a screen of ground glass g. When the screen was illuminated from without an observer at the eyepiece saw a rectangular patch of light—the face of the reflecting prism—surrounded by the field of light due to the phosphorescent surface. The brightness of this

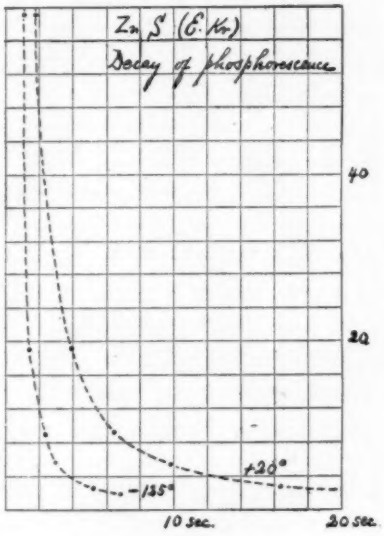

FIG. 5.

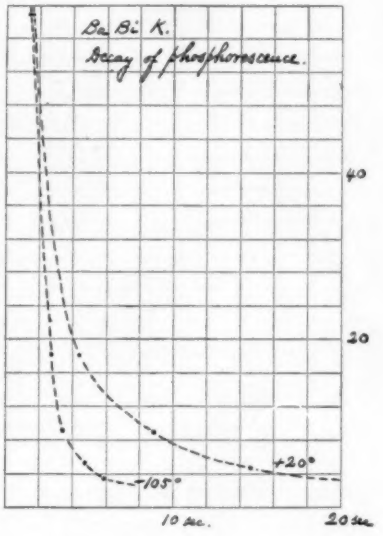

FIG. 6.

patch was varied, in making measurements, by the movement of a small frosted tungsten lamp (boxed in and viewed through a small aperture) which travelled along a photometer bar in the direction of the axis of the side tube.

To determine the curve of decay with this apparatus the comparison lamp was set at a selected point on the photometer bar, the shutter was opened for ten seconds to secure saturated exposure of the specimen under observation, and at the instant when the decaying phosphorescence had fallen to the degree of intensity which

balanced the light of the comparison lamp as determined from the appearance of the contrast field of the photometer, a record was made on the same chronograph sheet on which the closing of the shutter had been automatically registered.

This procedure was repeated with the comparison lamp at various positions on the bar. Typical results obtained in this way are

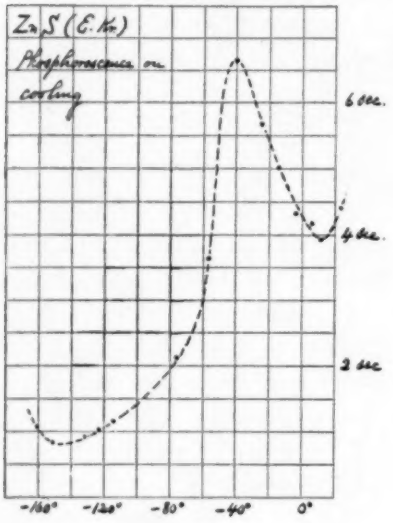

FIG. 7.

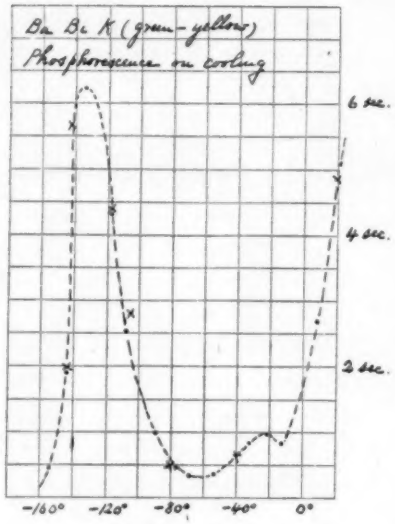

FIG. 8.

given in Figs. 5 and 6. Fig. 5 shows the curves of decay of phosphorescence in a sample of ZnS at $+20°$ and at $-125°$. In Fig. 6 similar in curves for a phosphorescent barium sulphide prepared by the method of Lenard and Klatt and having as its active metals bismuth and potassium are given for $+20°$ and $-105°$.

The more rapid decay exhibited by both of these substances at the low temperatures does not necessarily indicate lower initial intensity of phosphorescence. Indeed in the case of the Ba Bi K compound the initial intensity at $-105°$ which may be estimated from the decay curves by plotting these in the manner already described by Professor Merritt and myself[10] in which the reciprocal of the square root of the intensity is taken as ordinates is several times higher than the intensity at $+20°$.

[10] Nichols and Merritt, *Physical Review*, Vol. XXII., p. 280, 1906.

So marked are the fluctuations in the duration of phosphorescence in these substances on cooling that at many temperatures the effect dies down more rapidly than it can be followed with the apparatus just described. It is, however, possible to secure an almost complete record of the fluctuations of phosphorescence with temperature by allowing the substance to cool slowly throughout the entire range of temperatures. The photometer carriage is set at a convenient distance and records made of the times required for the phosphorescence to attain this intensity at the various temperatures

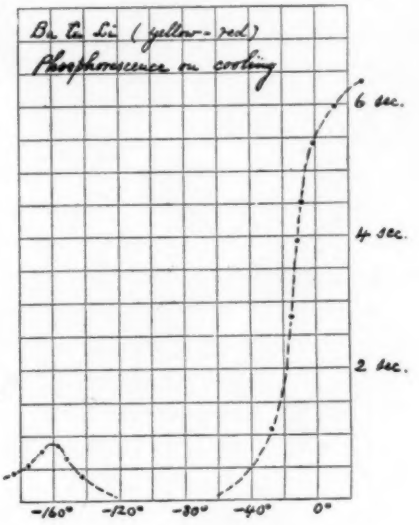

FIG. 9.

through which the substance passes in cooling. Measurements of this sort were made by Mr. Putnam and myself in the case of a number of phosphorescent sulphides. Three characteristic cases are shown in the curves in Figs. 7, 8 and 9. Two of these substances are those for which the decay curves have been given in the previous figures, namely, the phosphorescent zinc sulphide and the Ba Bi K compound. In all three of these cases it will be noted that the time required for the phosphorescence to fall to a given intensity varies greatly with the temperature and that the curves showing these changes have marked maxima and minima. In the

case of the zinc sulphide, for example, the longest duration observed was at —40° but there is evidently another maximum at some temperature above that of the room and still another at or below the temperature of liquid air. The curve for Ba Bi K shows a very pronounced and remarkable maximum at —132°, above and below which temperature the duration of phosphorescence falls off with great rapidity. Between —40° and —80° the duration is so short that measurements can scarcely be made with this apparatus. In the case of the third compound in question (barium sulphide with

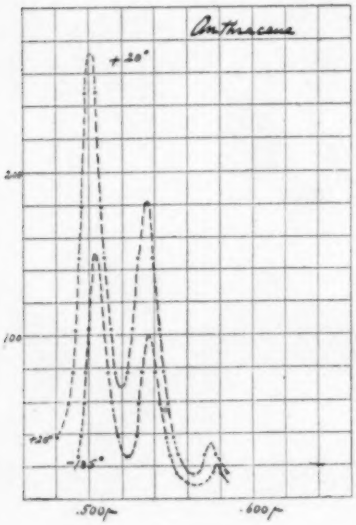

FIG. 10.

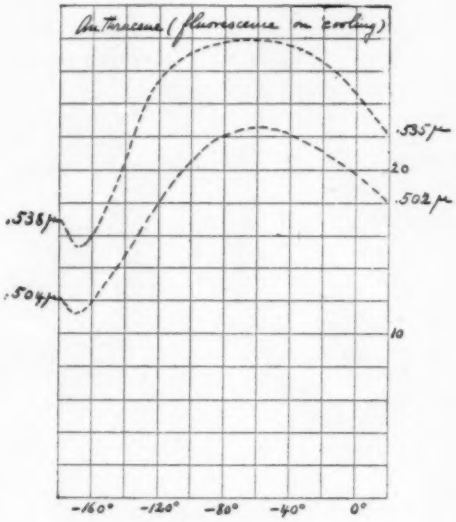

FIG. 11.

Fluorescence of solid anthracene.

copper and lithium as the active metals), see Fig. 9, the duration of phosphorescence falls off as the temperature diminishes until at about —60° it is difficult to observe the existence of any phosphorescence whatever. The fleeting glow at these temperatures appears of a different color from that observed either at higher or lower temperatures. As the temperature of liquid air is approached the duration increases again until it becomes measurable. It reaches a maximum at about —160° after which it begins once more to decrease.

The study of the fluorescence of these and other substances shows that the relation of fluorescence to phosphorescence is not so simple as at first appears. Observations with the spectrophotometer bring out various complexities in the fluorescence spectrum. Bands that seen with the spectroscope appear to be single are found to consist of two or more components more or less closely overlapping. Changes of temperature affect all wave-lengths of a single band in the same manner and, in some cases, neighboring bands are similarly affected. In the fluorescence spectrum of commercial anthracene for example, there are besides the blue and violet bands of the pure substance, two bright bands having their crests at .502 μ and .538 μ and a much fainter band with a maximum at .575 μ. At — 185° all three of these bands are reduced in intensity in nearly the same proportion (see Fig. 10). In the case of all three moreover the diminution is greater on the side towards the violet so that there is a slight shift of all three bands towards the red. The positions of the crests are now .504 μ, 538 μ and 577 μ respectively. At the temperature of liquid air moreover the bands are narrower and the yoke between them is much lower.

Observations upon the crests of the two brighter bands, as the substance is gradually cooled, show that the two crests rise and fall in intensity together preserving very nearly the same relative heights as indicated by the curves in Fig. 11.

This displacement of fluorescence bands towards the red on cooling is of frequent occurrence. In the case of the single band in the red-yellow of the fluorescence spectrum of solutions of resorufin in alcohol for instance (see Fig. 12) we find upon reducing the temperature from +20° C. to —95° C. that the intensity at the crest is reduced to about one half and the band is narrower than at room temperature. There is however no appreciable shift. At —165° C. the whole band is shifted to the red and there is further narrowing which shows itself in the steeper slope of the curve on the violet side. The intensity however is the same as at —95° C. Further cooling to —185° C. greatly increases the intensity without further shift. Fig. 13 shows the variations in the brightness of the crest of this band throughout the range from +20° to —185°. It

might be thought that since the solvent is alcohol which freezes at —112° the shift of the band is due to the change from a liquid to a solid solution, but this would not account for the changes occurring in the fluorescence of anthracene nor for the very marked shift towards the red observed in the case of willemite (Fig. 14).

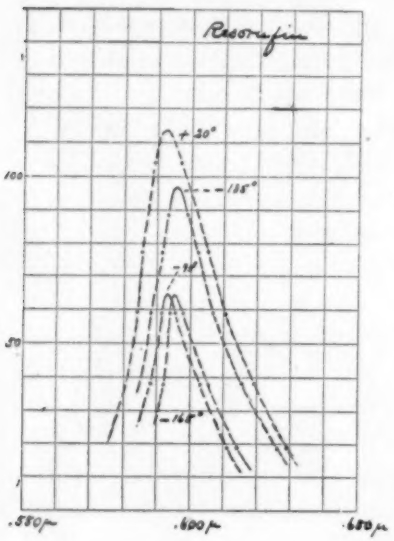

FIG. 12.

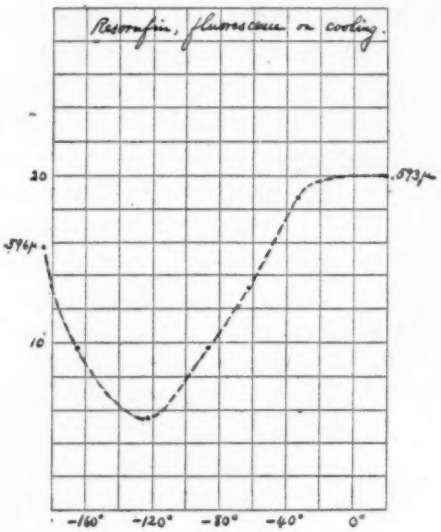

FIG. 13.

Fluorescence of resorufin.

In this fluorescent silicate, willemite, the band at +20° is evidently complex, a closely overlapping band towards the violet being indicated by the slight notch or shoulder at .51μ (Fig. 14). Upon cooling to —70° this component is suppressed and as a result the violet edge of the band is greatly shifted. Whether the shifting of the crest, which occurs on further cooling is altogether due to this cause cannot be definitely determined from these observations.

A very interesting example of a complex band exists in the case of a phosphorescent sulphide of strontium prepared by the method of Lenard and Klatt with bismuth as the active metal and a sodium salt as flux. Measurements of the fluorescence spectrum made with the spectrophotometer when this substance at +20° is excited by

the light of the mercury arc, give a curve of the form shown in Fig. 15. There is a narrow band with a sharp peak at wave-length. .494μ and a group of two or more much weaker, over-lapping bands towards the violet. At the temperature of liquid air the band towards the red is reduced in brightness and is shifted towards the violet, the group of bands of shorter wave-length, however, are greatly increased in intensity and the curve shows the presence of at least four crests, at .480μ, .474μ, .468μ and .463μ.

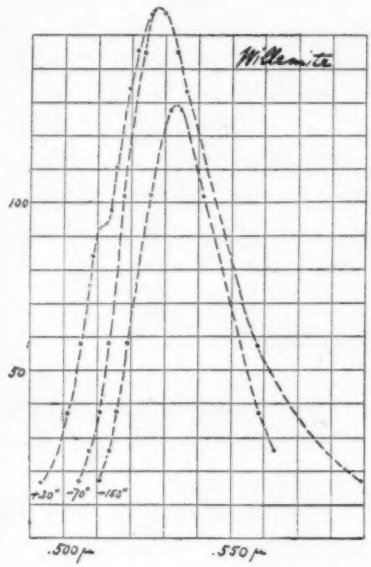

FIG. 14.

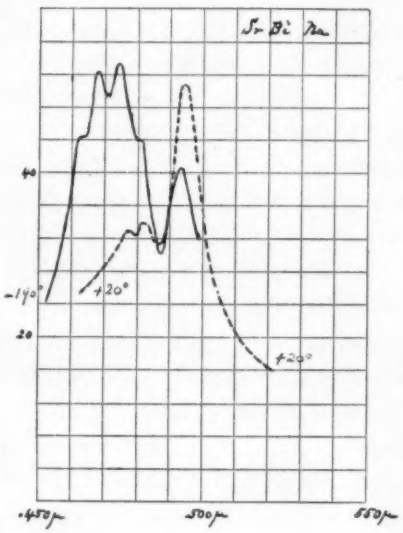

FIG. 15.

When viewed in the ordinary way with the spectroscope this entire group appears as a single broad band and indeed it has been so designated by Lenard[11] in a recent paper. When however we consider that each of its overlapping components is independently affected, by temperature as to wave-length, intensity and rate of decay it will be seen that any complete and quantitative study of the fluorescence and phosphorescence is a very complicated and difficult matter.

Numerous spectrophotometric measurements, of the spectra of

[11] Lenard, *Ann. der Physik*, IV., Vol. 31, p. 641, 1910.

fluorescent and phosphorescent substances made by Professor Merritt and the present writer, of which a few typical examples have been given in this paper, lead to the following general conclusions.

1. The emission spectra of fluorescent and phosphorescent bodies even when they appear to consist of a single broad band are frequently complex consisting of a group of overlapping bands.

2. The various components of a broad band vary in intensity (both relative and absolute) with the temperature.

3. Sometimes neighboring components of a band are similarly affected by a given change of temperature; sometimes they are oppositely affected, one component increasing in brightness while another diminishes.

4. Change of temperature is frequently accompanied by a shift of the bands of a fluorescence spectrum and this shift, which is sometimes toward the red and sometimes towards the violet, appears in many cases to be due to simultaneous and opposite changes in the intensity of overlapping components.

5. The rate of decay of phosphorescence depends upon the temperature and the complexity of the changes observed when the phosphorescent light is studied as a whole may probably be ascribed the independent variations, as to brightness, duration and position of the various overlapping bands of which the spectrum is composed.

6. Many of the changes in the color of fluorescence and phosphorescence may be ascribed to these independent variations in the intensity and differences in the duration of the overlapping components.

PHYSICS LABORATORY OF CORNELL UNIVERSITY,
April, 1910.

GERMINAL ANALYSIS THROUGH HYBRIDIZATION.

By GEORGE HARRISON SHULL.

(*Read April 23, 1910.*)

The study of the various characteristics of plants and animals as independent units has made hybridization a valuable instrument in experimental morphology, and has given to the name of Mendel an enduring place as a true prophet in the history of biological progress.

The importance of the Mendelian contribution can scarcely be over-estimated. Before the "re-discovery" a decade ago, no one but Mendel had given an approximately correct interpretation of the composition and behavior of hybrid progenies, and the process of hybridization was therefore of no particular consequence for general biology. The *hybrid individual* was taken as the unit and comparisons between the hybrids and their parents were made in generalized terms involving the general aspect or *tout ensemble*. As only rarely were all the characteristics of either parent recombined in one of the offspring, the phenomena of segregation and recombination were considered of relatively rare occurrence, and described in terms of atavism or "throwing back" to the ancestral condition.

An important cause for the long delay in the discovery of the Mendelian phenomena was the distinction made between the offspring of species-crosses, which alone were distinguished as "hybrids," and the cross-bred offspring of more closely related forms, which were stigmatized as "mongrels." The difficulty of making species-crosses, the consequent rarity of such hybrids, and the usually uniform type of the offspring produced, all gave the impression of their greater scientific importance at a time when rarity and uniformity of phenomena instead of their general occurrence and variability seem to have made the stronger appeal.

Koelreuter, the first hybridologist, started the current in this direction by devoting his attention so strongly as he did to the phenomenon of sterility in hybrids, which he considered an important test of the specific distinctness of the parents. The very fact of fertility in the progeny of a cross seemed in later years to terminate its interest for him and only in rare instances in his writings do we find any data as to the characteristics of individuals belonging to second and later generations.

Gaertner dealt with the subject of hybridization in a much broader way and arrived at many interesting generalizations. However, he also worked almost wholly with species-crosses, purposely choosing his material with as wide differences as possible in order to facilitate definiteness of descriptions, but in this very effort to gain definiteness, the opportunity for studying the second and later generations was usually lost through the sterility of the first generation hybrids. He did, however, make some studies on such well-known Mendelian material as peas, sweet peas and Indian corn, but only in the last did he study a second generation, and in this the complexities introduced by "xenia" were doubtless the chief cause of his failure to find the simple law of segregation.

Practically all other hybridizers from Gaertner's time on to the beginning of the present century, considered the mere securing of hybrid individuals and their systematic description as the matters of prime value. Thus it was that the *combination* phenomena of hybridization alone occupied the stage, and the separation of the parental characters and their recombination in different individuals was only imperfectly recognized as variability and returns to one or other of the two parental types.

Two French investigators, Godron and Naudin, who were working synchronously with Mendel, seem to have come very near sharing Mendel's great discovery, but each of these two investigators by a strange chance observed a different phase of the Mendelian phenomena, Godron reaching the conclusion that in mongrels ("métis") all progenies return in several generations to the parental types and then breed true, while Naudin thought he had demonstrated that the progenies continue to vary after the F_2 and

never become fixed. However, in the work of Godron and Naudin, their near discovery of Mendelian segregation was not due to a deliberate consideration of the various characteristics as units, but rather to the fact that several of the forms which they used in their cultures, differed from each other by single unit-characters, as exemplified for instance by the purple color of stems in *Datura Tatula,* contrasted with the green stem of *D. Stramonium,* or the usual prickly fruit of the Daturas contrasted with the smooth fruit of a var. "*capsulis inermibus.*"

The Mendelian method of following single characteristics possessed by the parents, not only into their F_1 progeny, but also through the second, third, and later generations, brought to light a regularity of behavior which has served to shift the stress from the simple combination phenomena involved in hybridization, to the phenomena of separation and recombination of such elementary differences as existed between the two parents.

The result of this important innovation of method has been to demonstrate beyond a peradventure, that many of the distinguishing characteristics of adult plants and animals are predetermined by corresponding differences in the constitution of the germ-cells; that these differences may be of an elementary character, capable of separation into different germ-cells; that when two parents used in any cross, differ by such elementary characters, half the resultant germ-cells have the capacity to produce any given elementary character of the one parent, the other half possess the capacity for the production of the corresponding or alternative characteristic of the other parent; that as a rule such unit-characters are wholly independent from one another and capable of rearrangement in every possible combination with one another; and, finally, that it is purely a matter of chance, which available type of sperm shall fertilize any given egg.

The separation of the unit-characteristics into different germ-cells in every possible combination with other characteristics gives the power in many cases to recognize all the unit-differences which served to distinguish the two parents. By the study of the hybrid progenies we are thus given an insight into certain phases of the

protoplasmic constitution and the "mechanism" of heredity, which has been totally unattainable by other means.

In making analyses of such hybrid progenies and in working out the nature and delimitations of the unit-differences involved in Mendelian crosses, no assumption need be made as to the ultimate nature of the "genes"[1] or determiners. The attitude of nearly all experimenters in the field of genetics is one of more or less consciously suspended judgment on this point, and I believe that no other attitude is justified at the present time. So far as I am aware no investigator of the Mendelian phenomena "sees only particles" as Dr. Riddle[2] has erroneously assumed, although it must be confessed that his speech does sometimes seem to symbolize them. The Mendelian interpretations do not "stand as a formidable block in the path of progress," nor as any block at all, since all terminology is more or less symbolic, and comes to mean new things as rapidly as new truths are brought to light. All investigators in this field will be appreciative of the service Dr. Riddle has performed in bringing to their notice the recognized facts in the process of melanin formation, though they can scarcely fail to regret his unfamiliarity with the present state of genetic science, and with the attitude of those engaged in the investigations. If he had been thus familiar with work in genetics, he might very easily have shown that the facts of melanin chemistry are in harmony with the mass of other data for which the "Mendelian interpretation" has proved so illuminating.

Although the question of epigenesis *versus* preformation is emphasized as a fundamental difference between Riddle's views and those of the Mendelians, this supposed difference is mainly imaginary. Riddle's assumption of different "strengths" in the germ-cells as a possible method of accounting for the production of different colors or other characters in adult animals, involves a preformation of the same order as that assumed by the investigators of

[1] The genes are the differences, of whatever nature, whose existence in the germ-cells determines the capacity of the unit-characters to be present or absent in the individuals developed from those germ-cells.

[2] Riddle, O., "Our Knowledge of Melanin Color Formation and its Bearing on the Mendelian Description of Heredity," *Biol. Bull.*, **16**: 316–351, May, 1909.

Mendelian phenomena. Every thremmatologist is too familiar with the facts of ontogeny to give the slightest credence to anything approaching the old embôitement hypothesis, but he must accept as a philosophical necessity the fact that there can be no action without an agent. There can be no "strength" without something to be strong. Preformation and epigenesis are simply inseparable phases of a single philosophical unity and any attempt to separate them is fallacious.

The statement that the "nature of present Mendelian interpretation and description inextricably commits to the 'doctrine of particles,'" presents Mendelism and its investigators in a false light, as no such commitment is involved. Despite the enormous activity and splendid progress that has been made in these ten years in tracing the Mendelian behavior until it has become evident that it is a well-nigh universal phenomenon,—no doubt practically co-extensive with sexual reproduction,—the changes in descriptive terminology to which Dr. Riddle deprecatingly refers, have been remarkably slight, and one reads Mendel's original account with wonder that it should still be so modern. Mendel's genius grasped the essentials of this type of inheritance so completely and presented it with such fulness and clarity, that it may doubtless always serve as a good elementary presentation of the subject. But while Mendel's paper is in such essential accord with "present interpretation" as to seem strictly modern, there occurs throughout his whole admirable discussion, not one word of suggestion that he attributes the occurrence of any external character to the presence of an internal particle.

Modern Mendelians as a rule have specifically declined to postulate the presence of material "particles" as the physical bases of unit-characters. Bateson, who has done more than any other to demonstrate the wide applicability of the Mendelian method, clearly placed himself from the first in opposition to any purely morphological interpretation of Mendelian phenomena by giving to his reports to the evolution committee the title: "Experimental Studies in the *Physiology* of Heredity," and he has from first to last carefully guarded all statements with reference to the nature of the genes, in such manner as to be entirely non-committal. Other investigators have either wholly ignored the question, or have usually

couched their suggestions in such terms as to show that they were open to any new light upon the subject.

Although I have never looked upon the Weismannian conception of character-determiners as at all plausible, I do not agree with Dr. Spillman[3] that the facts presented by Riddle "*disprove*" the "particle hypothesis." The only manner in which Riddle despatched(?) the "particle hypothesis" was by ruling the observed facts of Mendelian heredity out of court. If the Mendelian phenomena are real, and no one can do careful investigation in this field without becoming convinced that they are, the postulation of "particles" or "bullets" having certain chemical and physiological properties, and behaving during the reproductive process in some such manner as the cytologists are fairly agreed that the chromosomes behave, would offer a complete explanation, and the correctness of such an explanation can not be *disproved* except by proving that some other method of determination is the true one. However, while the particle hypothesis is not disproved, I have no doubt that the Weismannian, and perhaps also the De Vriesian conception of the genes will seem less and less plausible as new facts accumulate.

In Dr. Spillman's[4] brilliant development of what he calls the "teleone hypothesis," a suggestion is offered which virtually makes the chromosomes the "bullets" whose differential properties determine the unit-characters. This interpretation of the Mendelian phenomena has much to commend it, especially as it calls for no structure and no type of behavior which are not already generally recognized as being universally present in the formation of the germ-cells, and it has the added advantage that it seems to be capable of experimental tests.

I can not see, however, that Dr. Spillman has presented "an explanation of Mendelian phenomena without resorting to the idea of unit-characters." If he appears to do so, it is only because he gives to them a new name. The unit-characters are the empirical phenomena for whose explanation the "bullets," "teleones" or genes of any other sort, are devised. It is no new idea that these

[3] In conversation.

[4] Spillman, W. J., "Mendelian Phenomena Without De Vriesian Theory," *Amer. Nat.*, 44: 214–228, April, 1910.

unit-characters are "differentials," as this was recognized by Mendel himself and has been common knowledge to all investigators of Mendelian heredity since.

The length of hair in guinea-pigs and rabbits, the stature of peas, sweet peas, beans, etc., the length of styles in *Primula* and *Œnothera,* density of the heads in wheat and barley, and in fact practically all other characters with which Mendelian investigators have worked, have been so obviously differentials that it is impossible to assume that any Mendelian has ever meant anything else by the expression, "unit-character."

This being true, the contention of Riddle that even in the absence of a given unit-character there is not a complete absence of the particular manifestation in which the essence of that unit-character consisted, or in other words, that the unit-character is simply a phase or "strength" of some "rather general protoplasmic power," is not likely to seriously disturb the Mendelians, since that is a fact with which they have long been familiar.

It appears to me that the unnecessary shifting of the terminology of clearly distinguishable empirical phenomena is undesirable. The unit-characters are *real things* capable of repeated demonstration. They are still differential *characters,* and possess the capacity to behave as *units,* entering into various combinations with other unit-characters and capable of reëxtraction from them, or of being absent altogether, regardless of the manner in which their behavior is explained. The genes, on the other hand,—the ultimate organs of the protoplasm or conditions of the protoplasmic substance upon whose existence depends the capacity to give certain series of reactions, or to pass through certain cycles of ontogenetic development,—are purely inferential. Their nature is not yet capable of demonstration. They are "unknown gods" to whom each new prophet may appropriately apply a new name whenever he ascribes to them new attributes.

While the ultimate nature of the genes lies wholly beyond the powers of present-day analysis, and there is nothing therefore to warrant a departure from the prevailing attitude of suspended judgment, the more intimately the unit-characters themselves are studied, the better will be the basis provided for an understanding of their

common properties, and thus finally for an approximation to the nature of the genes which determine them.

The most hopeful directions of approach in the effort to learn more of the true inwardness of the unit-characters, are those of chemical analysis and experimental cytology. As applied to unit-characters, these are almost untouched fields at present, though several investigators have made a beginning. Miss Wheldale, especially, has made a hopeful beginning in the investigation of the chemistry of anthocyanin colors which have continually exhibited typical Mendelian behavior. Several unit-characters which have been recognized and described heretofore only in terms of color-factors, now seem to be capable of description in terms of a chromogen (present in all sweet peas and stocks investigated), and of activators, peroxidases, peroxides, and reducers, thus making the various colors "the result of definite oxidation stages of the chromogen." Riddle has come to much the same conclusion in regard to the nature of the melanin colors, from a consideration of the work of Bertrand, Gessard, Spiegler and others.

In experimental cytology there seems to have been nothing done as yet, which can throw light on the nature of those unit-characters involving the structure and size of parts. How are the number and direction of cell-divisions that shall take place in any cell-lineage determined? Are these also referrable to the presence of definite chemical substances or to definite configurations of protoplasmic molecules? To these questions I believe no satisfactory answer is now possible, but that these processes are controlled in many instances by characteristics possessed by the germ-cells, rests upon aboundant experimental evidence.

While waiting for further information from the chemist and the cytologist, there is still abundant room for the work of the experimental breeder. Owing to the characteristic distribution of the genes at the time of germ-cell formation already described, Mendelian hybridization provides a partial analysis of the germ-plasm, and thus gives some insight into the constitution of living protoplasm. It is of great importance that such analysis be continued until all the unit-differences of plants and animals have been studied,

for only when this is done can the full scope and significance of the Mendelian phenomena be understood.

It need scarcely be pointed out that the complete tracing of the germinal analysis which takes place in Mendelian hybrids, is attended with many difficulties. The unit-characters represent capacities for reaction in a certain, very specific way to given conditions of environment. Individuals having the same unit-composition may react in a totally different way to a different environmental complex. Some unit-characters are so sensitive to slight differences of environment that they offer a wide range of fluctuation, or they may represent such a slight differential as to be readily distinguishable only in their plus-fluctuations. Two or more unit-characters may even be indistinguishable from one another as Nilsson-Ehle[5] has shown to be the case in certain unit-characters of wheat and oats, and East[6] in endosperm colors of corn. Many unit-characters are quite invisible except when occurring in combination with some one or more other characters, and this fact has led to what is called the "factor hypothesis." That the factors are real unit-characters, differing in no essential way from ordinarily visible unit-characters, is now in a fair way to be demonstrated by such work as that of Miss Wheldale, and others who are working along similar lines. The implication by some writers that the factor hypothesis is a late development of Mendelism is not correct, as Mendel himself suggested it tentatively. The difficulty of tracing invisible characters necessarily made the development of knowledge regarding them slower than that regarding the easily visible characters, but the essential correctness of Mendel's suggestion has been abundantly substantiated.

All of the foregoing difficulties can be overcome, and are continually being overcome by careful analysis and patient, long-continued breeding tests.

Finally, since we are examining the Mendelian process as one of germinal analysis it is appropriate to discuss for a moment the

[5] Nilsson-Ehle, H., "Kreuzungsuntersuchungen an Hafer und Weizen," 4to, pp. 122, 1909, Lund: Hakan Ohlsson.

[6] East, E. M., "A Mendelian Interpretation of Variation that is Apparently Continuous," *Amer. Nat.*, **44**, 65–82, Feb., 1910.

"insoluble residue." Although Mendelian behavior has proved to be nearly universal in those sexually produced plants and animals which are capable of breeding together normally, there are certain clear limitations to the process of analysis. Several instances are known in which differential characters are not segregated, and no analysis takes place with respect to these characters, even when most of the differential characters of the same plants or animals Mendelize in a perfectly typical manner. The relative frequency of this type of behavior may be greater than is now supposed but so far as clear evidence is available permanently blended inheritance of this type is relatively rare except in species-crosses, and in these latter the data is usually too scanty for safe generalization.

Aside from these cases which show a distinctly non-Mendelian mode of inheritance, it must be remembered that Mendelian analysis can be made only in the presence of differential unit-characters possessed by individuals *capable of life and of sexual reproduction,* and that therefore, there can be no test, except under rare circumstances, of the Mendelian nature of the more fundamental vital characters. This leaves it an open question whether the whole of the germ-plasm is a complex of such genes as those which give rise to the phenomena of unit-characters, or whether, with its wonderful general powers of assimilation, growth and reproduction, it consists of a great nucleus of which the genes are relatively superficial structural characteristics.

However, although nothing inconsistent with life and reproduction are ordinarily amenable to Mendelian analysis, this need not detract from the fundamental importance of unit-characters in the study of heredity and evolution, for the phenomena appearing in these fields are subject to exactly the same limitations. All that we know about heredity and evolution *must start* with a plasma capable of life and reproduction.

While thus leaving the absolutely fundamental characteristics of living matter untouched, the Mendelian method and its results have brought into harmonious relations many of the most diverse phenomena of phylogenetic differentiation and it is only fair to assume that they hold still greater promise for the future.

THE NEW VIEWS ABOUT REVERSION.

By C. B. DAVENPORT.

(*Read April 23, 1910.*)

To the general principle that "like begets like" striking exceptions are not infrequently found. These exceptional cases fall into two classes. In the one class the child possesses some character not visible in either parent but found in a grandparent *e. g.*, blue iris in the chlidren of brown-eyed parents. This is known as *atavism*. In the other class, the child possesses some character not visible in immediate relatives but found in some remote ancestor or even ancestral species; *e. g.*, the reappearance of the Jungle fowl plumage among domesticated poultry. This is known as *reversion*.

Of these two phenomena reversion is the more striking and the explanation that has been current until recently, even among biologists, and is still common among breeders is essentially that of Darwin[1]—"An inherent tendency to reversion is evolved through some disturbance in the organization caused by the act of crossing."

The new explanation is based on the principle that the unit of inheritance is not the individual but some *characteristic* of an organism. Paternal or maternal characteristics are not inherited en masse for the most part but each character independently of every other. A second principle, no less important, is that inheritance is not truly from the parents but from the germ plasm; it is not the adult characters that are inherited but something in the germ cells that will eventually determine those characters. One may dispute the hypothesis of pre-formation in the germ but one can not deny that the egg of an ox is predetermined, certain conditions being fulfilled, to develop into an ox while the egg of man is similarly predetermined to develop into a man. There are probably numerous points of difference in the minute chemical structures of these

[1] Variation of Animals and Plants under Domestication," Chapter XIII.

two eggs and these differences determine the different end results. They may be called *determiners*. Ordinarily, when parents are similar, each unit character of the offspring develops from two similar determiners—one paternal and one maternal. Thus in its origin any unit character is duplex. When, however, the determiner is found in only one of the parents the character is simplex. Now such a character frequently develops imperfectly because of the partial stimulus to development.

If in an individual any character is simplex then the germ cells of that individual are typically of two kinds; half have the determiner for the character and half lack such determiner. Now if two such individuals be parents the chances of the uniting of (*a*) two germ cells with the determiner, (*b*) two germ cells without the determiner, and (*c*) one with and one without are as 1:1:2, or 25 per cent. of the offspring will have the character duplex; 50 per cent. will have it simplex, while 25 per cent. will lack the character —and will thus resemble one of the grandparents!

To illustrate. If the two grandfathers have blue eyes and both grandmothers brown eyes then the parents may both have simplex brown eyes; they will both form germ cells of which 50 per cent. have and 50 per cent. lack the determiner to form brown iris pigment. From such brown-eyed parents one child in four will have blue eyes like the grandfathers. This is atavism. Cases of atavism can, in general, be explained on the same ground as atavism to blue-eyed grandparents. Complications are indeed induced by sex-limited heredity, illustrated by the horns of sheep which appear, when simplex, only in males of certain strains. A further complication is seen in cases of apparent or partial blending as in human skin color. But in the great majority of cases atavism is a simple reappearance in one fourth of the offspring of the absence of a character due to the simplex nature of the character in both parents.

Reversion in the strict sense has a more complicated explanation. It depends in general on the circumstance that many apparently simple organs or color patterns or colors are really complex and require the coöperation of two or more elementary characteristics called *factors*. For generations a particular character may

not appear but when two parents together produce the required factors the combination may be an apparently new, compound character; which we find elsewhere only in remote ancestry.

The facts of reversion are most notorious among domesticated animals and plants. The reason is that man has preserved just those strains of germ plasm that are peculiar in the absence of some typical characteristic or the presence of some new characteristic. These new conditions either cause the ancestral condition to fail of development or mask it over. In hybridizing we restore the factor that is missing from one strain by introducing it from another strain; or we remove the added factor that veils the ancestral condition. Thus the ancestral condition is restored—a reversion occurs.

The foregoing general statement may now be illustrated by some examples.[2] The goldfinch, which has plain chestnut sides, when crossed with a plain yellow canary produced hybrids that have stripes on back and flanks. Darwin mentions this case[3] and adds: "this streaking must be derived from the original wild canary." The results of breeding indicate that the yellow canary has one factor for these stripes—as it were, the potential pattern—but no pigment to bring it out. Adding the factor of pigment from the goldfinch the pattern appears in the offspring.

Reversion in poultry was studied by Darwin. He crossed a White Silkie hen with a Spanish cock which is perfectly black except for the iridescent glossy black in hackle, saddle, wing bar and some of the tail feathers. "As the cocks grew old one . . . became a gorgeous bird. When stalking about it closely resembled the wild *Gallus bankiva,* but with the red feathers rather darker." The hens were black. I have made the same cross with the same result. Moreover, when the hybrids were mated together some of the females as well as males assumed a perfectly typical Jungle fowl coloration. The "reversion" was now complete.

The interpretation of this case on the factor hypothesis is some-

[2] The colored lantern slide illustrations are not here reproduced; they appear in part in the author's works entitled, "Inheritance in Poultry," "Inheritance in Canaries," and "Inheritance of Characteristics in Domestic Fowl," all published by the Carnegie Institution of Washington.

[3] Var. Dom. A. and P., Chap. XIII.

what complex but perfectly clear. All fowl except the booted races (which are of Asiatic origin and allied to the Aseel fowl) contain the determiner—complex for the Jungle fowl color pattern. We may call it J. This factor alone is impotent without a color-producing enzyme (C). The Silkie fowl apparently lacks this in the plumage and so remains colorless. The Spanish has it and so produces the Jungle pattern of which the red portion is nearly coincident with the glossy portion of the Spanish plumage. But the Spanish has an additional factor, an additional black coat (N), which turns the red part of the pattern black. Thus the Spanish color factors are CJN whereas those of the White Silkie are cJn, the small letters indicating the absence of the factors concerned. When the germ cells of the two races fuse the fertilized egg contains factors CcJ_2Nn; which means, the color enzyme is simplex, the Jungle pattern is duplex and the supermelanic factor is simplex. Since N is simplex it is insufficient to cover all of the red in the male, where it is strongest and so the males show some red, only, as Darwin says, it is darker than in the Jungle fowl. Now the germ cells of these hybrids have their characters all simplex: and they are consequently of four kinds: viz: CJN, CJn, cJN, cJn. If two such hybrids be mated their germ cells unite at random. If two germ cells of the first type unite a black bird results; if two of the second type Games result; if two of the other two types unite whites result. I reared 362 offspring from the hybrids; the relation of expected to observed birds of each type of color is shown on Table I.

TABLE I.

	Black.	White.	Game.
Expected	205	90	67
Observed	210	95	57

One sees that it is not hybridizing *per se* that produces the Game or Jungle coloration, else all would be so colored. It is the union of the requisite ancestral factors one or more of which are missing from the domesticated, fancy strains.

Again, if a White Silkie be crossed with a White Leghorn, the offspring are all white except that the males show some red in those parts of the plumage that are red in the Jungle fowl. In the second

generation some individuals, both males and females, show a typical Jungle fowl coloration. In this case the factors in the White Leghorn are the same as in the Black Spanish with the addition of another—the whitening factor (W), probably an antienzyme that stops the work of the pigmentation factors. Thus the formula of the White Leghorn is CJNW and its hybrids with the Silkie have the formula CcJ_2NnWw. The germ cells of the hybrids are of eight kinds, namely, CJNW, CJNw, CJnW, CJnw, cJNW, cJNw, cJnW, cJnw. These give 64 combinations in the fertilized eggs of the second hybrid generation. I raised only 85 chicks. The relation of expected and observed numbers is given in Table II. It will be seen that realization runs close to expectation.

TABLE II.

	White. (Including F_1 Type of Color.)	Game.	Black.
Expected	69	12	4
Observed	68	16	1

Finally, I may refer to a cross between the Black Cochin and the Buff Cochin. The Black Cochin has the color factor C and it has the supermelanic coat, but it seems to lack the red of the Jungle type of coloration. This modified Jungle type may be called I. The Buff Cochin is like the Black Cochin with the addition of a superxanthic coat (X) which produces the uniform red color. In the second hybrid generation these factors should appear in the combinations shown in Table III.

TABLE III.

1.....$C_2I_2N_2X_2$..... Black	2.....$C_2IiN_2X_2$..... Black	1.....$C_2i_2N_2X_2$..... Black
2.....$C_2I_2N_2Xx$..... Black	4.....C_2IiN_2Xx..... Black	2.....$C_2i_2N_2Xx$..... Black
1.....$C_2I_2N_2x_2$..... Black	2.....$C_2IiN_2x_2$..... Black	1.....$C_2i_2N_2x_2$..... Black
2.....$C_2I_2NnX_2$..... Black and red	4.....C_2IiNnX_2..... Black and red	2.....$C_2i_2NnX_2$..... Black and red
4.....C_2I_2NnXx..... Black	8.....$C_2IiNnXx$..... Black	4.....C_2i_2NnXx..... Black
2.....$C_2I_2Nnx_2$..... Black	4.....C_2IiNnx_2..... Black	2.....$C_2i_2Nnx_2$..... Black
1.....$C_2I_2n_2X_2$..... Buff	2.....$C_2Iin_2X_2$..... Buff	1.....$C_2i_2n_2X_2$..... Buff
2.....$C_2I_2n_2Xx$..... Buff	4.....C_2Iin_2Xx..... Buff	2.....$C_2i_2n_2Xx$..... Buff
1.....$C_2I_2n_2x_2$..... White	2.....$C_2Iin_2x_2$..... White	1.....$C_2i_2n_2x_2$..... White

each combination having the prefixed frequency and yielding the color indicated. Uniting black and black-and-reds, since red ap-

pears in one sex only and not until late in life, we get the relations between the calculated and observed proportions in 86 offspring shown in Table IV. Here again the observed distribution agrees with the hypothesis.

TABLE IV.

	Black and Black and Red.	Buff.	White.
Expected	65	16	5
Observed	61	17	8

We may conclude, then, that reversion is not due to the act of crossing in and of itself. It is rather due to the restoration of the ancestral factors, neither more nor fewer. The ancestral combination occurs in by no means all of the hybrids but only in a predictable proportion.

In conclusion, a suggestion may be offered as to the frequently observed fact of reversion to the ancestral coloration of domestic fowl which have become feral, as, *e. g.*, in the Hawaiian Islands. Darwin suggests that at least part of the reversion of the domesticated animals that have run wild must be due to the new conditions of life. One observation that I have made sheds some light on the question. When domestic races run wild much intermingling of races occurs and the primitive type of coloration, among others, recurs. When, as is usually the case, this is better fitted to survive because of inconspicuousness or other advantage, it will tend to escape the general slaughter. That selective elimination is real in poultry is shown by an experience of mine. In an open field about 300 chicks ran at large. About 40 per cent. of them were white, 40 per cent. black and 20 per cent. penciled or striped. Twenty-four were killed by crows—all either solid white or solid black except one that was coarsely mottled gray and buff. It is obvious that the self-colored poultry are at a disadvantage because of their greater conspicuousness, and they must be, in time, eliminated, leaving only the striped or penciled birds—those of the ancestral type of color. Reversion is here not a germinal but an environmental result, due, however, not to climate but to organic enemies.

FURTHER NOTES ON BURIAL CUSTOMS, AUSTRALIA.

By R. H. MATHEWS, L. S.

(*Read May 7, 1910.*)

In previous numbers of this journal[1] I have reported some peculiar burial customs and stones used in magical ceremonies by the Australian aborigines. As the subject has been well received, I beg to submit some additional information obtained by me during a number of years when visiting the Darling River between Brewarrina and Menindee.

I have before described the so-called "widows' caps" and oval balls of kopai, placed upon native graves. Another emblem of mourning sometimes found at aboriginal burying places in the Darling Valley was made as follows: A quantity of burnt gypsum, ground fine and mixed with sand or ashes, to which water was added, and the whole worked into a somewhat coniform cylindrical mass about a foot or fifteen inches long. The large end, or base, of the cylinder, was sometimes elliptical and sometimes approximately circular, having the major diameter from about 5 up to 8 inches, which gradually diminished till near the other end, or apex, which was rounded off like the end of an immense egg. See Fig. 1. In the basal end a deep recess was made, reaching back 6 or 8 inches, and in the largest examples more than a foot, into the middle of the cylinder, resembling in shape the interior of an immense wine glass or goblet. The great depth of this cavity in proportion to its diameter, and its conical shape shows that these articles were not suitable for head ornaments.

The largest example of this sort of article which has yet come under my notice is one in my own private collection, illustrated in the accompanying drawing. Unfortunately, the smaller end was broken off before it was found, leaving the specimen open at both extremi-

[1] Proc. Amer. Philos. Soc., Vol. 48, pp. 1–7, 313–318, and 460–462, with illustrations.

ties, with a cylindrical cavity reaching right through it, like a piece of drain-pipe. The thickness of the shell is irregular, being greatest near the base and middle of the shaft, where it is in places about two inches, thinning out to intermediate thicknesses down to less than half an inch at other portions. The outside of the wall or shell

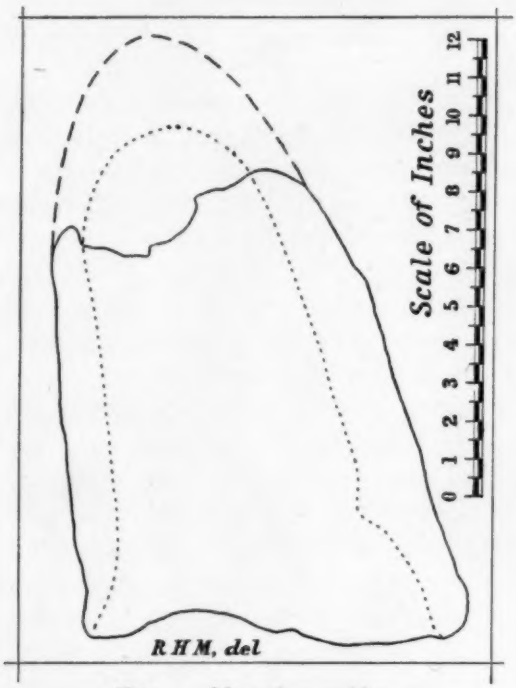

FIG. 1. Mourning emblem.

of the cylinder in its present damaged state is 13½ inches, but in its original state it probably measured about 16 inches, as indicated by broken lines in the drawing.

At the base, which is only slighly damaged, the longest diameter of the cavity or funnel is 8¾ inches, and the shortest 6 inches. The corresponding internal diameters of the orifice at the smaller end are 5½ and 4¾ inches respectively. The outside measurement of the circumference at the base is 28¾ inches and a similar outside measurement at the smaller end is 23 inches. The original circumference has evidently been a good deal reduced by the wasting away

of the outer surface by the weather and wind-blown sand, during many years of exposure.

For the purpose of more fully illustrating this exceptionally large specimen, I have introduced a photograph, Fig. 2, which shows the base or larger end of it, with a view right through the hollow interior to the other extremity. Near the distal end of the funnel

FIG. 2. Mourning emblem. View through the interior.

shaped cavity there is a discolored streak in the wall or shell, which can be seen in the photograph. Such a mark could have been caused by a stoppage of the work or additional material, which was not quite of the same shade along the joining line. There is a thin, irregularly shaped patch on the outside of the cylinder, which was evidently put on after the main trunk had been completed, either to secure a uniformly rounded contour or to remedy some defect in the original structure.

When the specimen was discovered, it was lying in the position shown in Fig. 2, with all the lower part embedded in the sandy bank of Lake Tongo, and had apparently lain in that position for a long time. The upper half, from *a* right back to the other end, was fully exposed to the weather for many years, and is consequently

much diminished in thickness by disintegration. It is much the thinnest part of the shell, being in places less than half an inch thick. The lower half of the photograph represents the thickest part of the shell from the front to the rear.

My specimen was found on Tongo Station, near Lake Tongo, which flows into the Paroo River. Tongo is in the county of Fitzgerald, in the northwestern portion of New South Wales, about 80 miles north-northeast from Wilcannia, and is approximately in latitude 30° 30′ and longitude 143° 40′.

A somewhat similar specimen to that illustrated, but smaller, was found some years ago a few miles northwest from Tilpa, Darling River, and is now in a private collection to which I was allowed access. I had not time to make a complete drawing, but I took the following measurements. Complete outside length from base to apex, 12½ inches. The cavity in the base occupies the whole of the interior of the article, extending back in a conical form for 9 inches. The longer diameter of the orifice at the base is 7¾ inches, and the shorter 7 inches. There are no marks of a net on the inner wall and it is improbable that such ever existed. The circumference at the base, outside measurement, is 30 inches. The shell is somewhat thin throughout, ranging from a quarter to three quarters of an inch thick, until near the top of the cone, where it is about 3 inches in thickness. Like my own specimen, it has been reduced in size by exposure to the weather.

Another specimen which I have seen is a solid conical mass of kopai about ten inches long and six inches in diameter at the base or larger end. In the base is a shallow concavity, the depth of which is only about an inch and three quarters, without any indication of the marks of a net. Such an article could not be worn on one's head, because unless it were kept continually balanced, it would fall off. Its great weight would also be prohibitive. In my opinion, both this and the last described specimen, were not intended for wear, but were made for the purpose of being deposited upon graves by the relatives of the parties interred. This was done immediately after the burial, whereas the widow's cap was not deposited till the termination of her period of mourning.

As regards the purpose of articles such as that now illustrated, it is hard to obtain full particulars, because they are not used by the remnants of the tribes now living on the Darling River. It is not likely that they have been worn on the head, like the "widows' caps" described by me last year,[2] because the opening in some of them is too small to fit any adult skull, whilst others are too large and heavy. The great depth of the hollow—13 inches in my specimen—would be needless as a receptable for the head; and there are no impressions of a net on the inner wall similar to those found on "widows' caps." An old black fellow whom the white people called "Jimmy," a head man of the Ngunnhalgu tribe, who resided most of his later years at Marra Station, on the Darling, and who died about ten years ago, said the articles with the deep cavities were not worn on the head, but were laid upon the graves of old men and women of tribal importance, in the same way that the kopai balls were deposited.[3]

Mr. J. E. Suttor writes me as follows:

> In 1880, while mustering cattle on the back part of Curranyalpa run, I came across two old black men and a woman camped at a waterhole. They had shifted out from the Darling river to hunt opossums for the skins. The old woman was lying in the camp very sick. A few days later the two black fellows passed my camp, which was about five miles from their own, and told me the old woman had died. Going that way a copule of days afterwards I found the grave on a pine ridge close by the camp I had previously seen, and upon it were lying two hollowed kopai articles somewhat resembling widows' caps. At the place where the camp fire had been was a piece of bark, with the remains of kopai plaster upon it, together with some lumps of kopai, burnt and ready to break up, if more had been required.

The woman's husband and the other man, who was probably a relative, had each left a token of their sorrow upon the grave before they went away.

It is well known that human skulls were used as water vessels by the aborigines in several parts of Australia. Mr. E. J. Eyre saw some drinking cups of this sort, and gives an illustration of one.[4] The tribes referred to by Mr. Eyre adjoined the Darling River

[2] Proc. Amer. Philos. Soc., Vol 48, pp. 316–318, Figs. 5 and 6.

[3] *Op. cit.*, pp. 313–315, Figs. 1 to 4.

[4] *Journs. Expeds. Discov. Cent. Aust.* (London, 18—), Vol. 2, pp. 310, 316 and 511, plate IV., fig. 20.

people on the west. When surveying on the Darling and Paroo Rivers in 1884–5, I met an old black fellow who had a skull among his paraphernalia, which he used for drinking purposes on ceremonial occasions. Old "Jimmy," already quoted, told me that in addition to their use as mourning emblems, the kopai articles were imitation skulls which the spirits of the dead were supposed to use for their water supply in that arid district.

In Fig. 1, which is drawn to scale, the firm or continuous line represents the exterior of the article in its present state, viewed from the side. The broken line at the top of the drawing indicates the supposed form when first manufactured. The dotted line shows the limit of the internal cavity, if the shell were transparent and one could see through it. The total length of the article, outside, by the assumed restoration, is 16 inches; and the depth of the internal hollow space, as restored, is about 13 inches. No impressions or marks of a net are visible upon any part of the inner wall.

The present weight of the article is just a little over 15 pounds. At a moderate estimate, the portion broken off would weigh about 3 pounds, making the weight of the complete article about 18 pounds. Then we must take into consideration that the whole outside surface has suffered by disintegration during many years' exposure to the weather. The same would apply to the inside surface of the cavity, though in a lesser degree. The original weight has also been diminished by the drying of the material in the sun for such a long period. The reduction in the weight due to the two combined causes mentioned is difficult to estimate; but judging by the worn and contracted appearance of many parts of the surface, I think 2 pounds could be allowed for it. This would bring the total weight of the article, when it left the maker, up to about 20 pounds.

Conclusion.

Before concluding this paper, it has been thought desirable to supply a few additional remarks respecting my three previous articles on ceremonial stones and burial customs, published in the Proceedings of this Society, Vol. 48, pp. 1–7, 313–318 and 360–362. When the present article is perused in conjunction with the three

papers quoted, the reader will have a fairly complete account of the customs dealt with.

Magic Stones.—In regard to the ceremonial or magic stones, old "Harry Perry," the black fellow already quoted, told me that among other uses, these stones were employed for bringing rain, and this statement was repeated by old "Jimmy," of Marra Station, and by other old blacks. An old man took one of these talismans and placed it in the fork of a tree, several feet from the ground, in such a way that the saucer-shaped depression in the base was uppermost. He then sat down and sang the usual rain-producing song, after which he went away to his camp. It was necessary that great secrecy should be observed, because if any person saw the operation it would be a failure.

Some of these magic stones were used for bringing "dust-storms" which are very common in that arid part of New South Wales, in which case the procedure was the same as for rain, excepting that the song was differently worded. Moreover, a stone to produce "dust-storms" was reddish in color, like those numbered 1 to 4 in Fig. 2, Vol. 48, p. 462.

It must be explained that the country along the valley of the Lower Darling and northward from that river to the Queensland boundary, comprises many large stretches of red-colored, sandy soil, upon which very little grass or herbage grows. When a strong gale sweeps over this district in a dry season, it disturbs the loose soil, and separates from it vast quantities of fine, reddish dust, which rise and darken the air like a fog, which is sometimes so dense that one cannot see more than a few yards in any direction. Such visitations are known as "dust-storms," and are also facetiously spoken of as "Darling showers."

On the approach of a "dust-storm," kangaroos, emus, etc., hurry away to the scrubs and timbered places, where they are in the habit of taking shelter in wet weather and in times of danger. The blacks are aware of this practice of the animals, and when they think a "dust-storm" is coming, a couple of men go away and hide themselves in one of these scrubs. Two or more scrubs may be manned in the same way. The hunters place themselves

in such a position that when the animals come moping about in the fogginess caused by the dense clouds of dust, they can be speared or clubbed without difficulty. When a "dust-storm" was wanted for hunting purposes, a man who had a reddish or dust-colored ceremonial stone, took charge of the function.

Another use of a "dust-storm" was to obliterate the foot-marks of men or animals. A party who had been out on a marauding or murdering expedition, would bring up a "dust-storm" to prevent their enemies from following their tracks. Or a party of hunters could be frustrated in their operations if an adverse conjurer brought up a "dust-storm."

Mr. Tobin, who has lived a long time in the Darling district, tells the following. During a very dry time at Enngonia, on the Warrego River, a few old black fellows were camped on the bank. They were believed to possess the paraphernalia requisite for performing all the supernatural feats professed by a medicine man. One day a stockowner and one or two of his friends visited the camp, and asked the black fellows how it was that they did not bring a downpour of rain. He jocularly said that he would give so much flour and tobacco to any of the old natives who could break up the drought. One of them, called "Gurara Charlie," who was very anxious to take advantage of the offer, talked the matter over with his fellow conjurers, but it transpired that the stone which he possessed was only a *dust*-producing implement. One of the other blacks, "Jimmy Kerrigan," said that he had the right sort of stone for making *rain*, and he undertook the job for the promised reward. He was, unfortunately, not successful on that occasion, but attributed his failure to the malignity of an adverse conjurer who lived somewhere down the river.

When the stones were used for producing an abundant supply of nardoo, or other grass seeds, or for the increase of game, as stated at page 7, Vol. 48, the words of the incantation sung by the old performer were varied to suit the case. Moreover, when it was thought that enough rain had fallen, the magic stones were employed for bringing about fine weather. And when it was desired to prevent a "dust-storm" from rising, or to shorten its

duration, these charms were likewise in requisition, with a suitable accompaniment.

Widows' Caps.—Although a widow's head-dress invariably consisted of a cap similar in shape to those illustrated at pages 316–317, Vol. 48, they were also worn by a woman for an adult son or daughter, or for a favorite brother or sister. Their use was not restricted to the women only. Old "Marra Jimmy," already quoted, said that men sometimes wore such a cap in mourning for their mothers, mother's sisters, their own elder sisters, their wives and other blood relatives of mature years. Generally speaking, however, the men used the kind of articles described in this paper, which were never worn on the head, but were deposited at the grave.

The facts just narrated would account for the comparatively large numbers of so-called "caps" which have been found on individual graves. Mr. T. Worsnop mentions four found on a grave, one of which weighed fourteen pounds.[5] A friend writes me that he has seen five caps similarly used. A station owner on the Darling River informs me that many years ago there was an aboriginal grave not far from his homestead, which had nearly a dozen articles which appeared to him to be caps, lying upon it. They were not all of one size, but comprised some very large ones, others of medium size, whilst others were smaller. In the cases just mentioned it is likely that some were widow's caps; some had possibly been worn by men; whilst others were manufactured as tributes of mourning. The latter kind could be placed upon the grave as soon as the body was buried, whereas a "cap" could not be deposited till the wearer's term of mourning had expired.

The "widow's cap" illustrated in a former article (p. 316, Vol. 48), is made from kopai, with only a small mixture of sand or ashes, because kopai is abundant over a large portion of the Darling valley. But on some of the tributaries of the Darling, such as the Macquarie, Mara, Bogan, etc., where gypsum is found only in small quantities, the mourning caps are made out of a brown-colored tenacious mud, obtained from the bottoms of waterholes and streams, without any admixture of gypsum. Yellow or reddish

[5] "Aborigines of Australia" (Adelaide, 1897), p. 62.

clay, sometimes found cropping out on the slopes of ridges, or banks of watercourses, was also utilized for the same purpose. The shape of the cap was the same, no matter what the material consisted of. Clay caps, when removed from the head, and exposed to the weather on a grave, soon became disintegrated and fell to pieces; hence none of the caps of this material have been preserved by the white people.

White is the favorite color for mourning among the Australian aborigines, but when it cannot be obtained other colors must be substituted for it. It is perhaps needless to add that a cap of any sort, whether made of kopai or mud, and whether worn by a man or a woman, was removed during sleeping hours. It was also left in camp when the wearer, of either sex, was away in search of food, or while doing any kind of work.

PARRAMATTA, N. S. WALES, March 5, 1910.

SOME RELATIONS BETWEEN SUBSTITUTION GROUP PROPERTIES AND ABSTRACT GROUPS.

By G. A. MILLER.

(*Received June 4, 1910.*)

Dyck observed that the necessary and sufficient condition that a transitive substitution group G of degree n is primitive is that its subgroup G_1 which is composed of all the substitutions of G which omit one letter is a maximal subgroup of G[1]. This establishes an important relation between primitive substitution groups and the properties of G considered as an abstract group. It has also been observed that abstract group properties correspond to the different degrees of transitivity of substitution groups[2], and that the number of ways in which an abstract group can be represented as a transitive substitution group can be directly deduced from the properties of the group. These and other known relations have done much towards uniting the theories of abstract groups and those of substitution groups, and towards making these theories mutually helpful. It is the object of the present paper to establish other important relations between these two theories, especially as regards abstract groups and simply transitive substitution groups.

§ 1. *Some properties of co-sets.*

If H represents any subgroup of index ρ under a group G all the operators of G may be arranged so as to give ρ distinct sets both as regards right-hand and as regards left-hand multiplication, in the following forms:[3]

$$G = H + HS_2 + HS_3 + \ldots + HS_\rho,$$
$$= H + S_2H + S_3H + \ldots + S_\rho H.$$

[1] *Mathematische Annalen*, vol. 22 (1883), p. 94.
[2] *Messenger of Mathematics*, vol. 28 (1899), p. 107.
[3] *Bulletin of the American Mathematical Society*, vol. 16 (1910), p. 454.

The sets HS_α, $S_\alpha H$ ($\alpha = 2, 3, \ldots, \rho$) are known as *co-sets* of G as regards H. Galois called attention to the importance of the case when each $HS_\alpha = S_\alpha H$ for every operator of H. That is, for every operator of H in the first member there is some operator of H in the second member so that this equation may be satisfied. The necessary and sufficient condition that H is invariant under G is that such equations may be established for every value of α from 2 to ρ.

The co-sets HS_α. $S_\alpha H$ will be called right and left co-sets respectively. The totality of these co-sets is independent of the choice of the operators $S_2, S_3, \ldots, S$; that is, there is only one category of right co-set, and only one of left co-sets as regards any given subgroup. Each left co-set is composed of the inverses of all the operators in a right co-set and vice versa. Hence we may say that the necessary and sufficient condition that a subgroup H is invariant under a group G is that every right co-set of G as regards H is identical with some left co-set as regards H, or that every left co-set is identical with some such right co-set. In other words, the necessary and sufficient condition that H is invariant under G is that the number of distinct co-sets to which H gives rise is equal to its index under G diminished by unity, or that the totality of its right co-sets is identical with the totality of its left co-sets. This theorem is included in the theorem that the necessary and sufficient condition that H is invariant under a right co-set is that this co-set is identical with some left co-set, or vice versa.

With the extreme case in which each right co-set is identical with some left co-set we may contrast the other extreme case when each right co-set has some operator in common with every left co-set. It has been seen that H is invariant in the first case and we shall see that it gives rise to a multiply transitive substitution group (K)[4] in the second case, excluding the trivial case when the order of K is 2. In the proof of this theorem it will at first be assumed that H is neither invariant under G nor does it involve any invariant subgroup of G besides the identity. That is, we shall at first assume that K is a transitive substitution group which is simply isomorphic with G.

[4] Dyck, *Mathematische Annalen*, vol. 22 (1883), p. 91.

The subgroup (K_1) which is composed of all the substitutions of K which omit a given letter a is simply isomorphic with H. Hence the co-sets of G as regards H have the same properties as the co-sets of K as regards K_1. In the latter case, each of the right co-sets is composed of all the substitutions of K which replace a by the same letter, while each of the left co-sets replaces a by all the letters of a system of intransitivity of K_1. Hence it results that in this case the necessary and sufficient condition that K is multiply transitive is that each right co-set as regards K_1 has at least one operator in common with every left co-set.

When H is invariant under G it results that K is a regular group and the theorem given above requires no proof since a regular group cannot be multiply transitive. When H involves an invariant subgroup of G but is not itself invariant under G, K will be the quotient group of G with respect to the maximal invariant subgroup of H which is also invariant under G. It is evident that the reasoning employed above applies directly to this quotient group, and hence we have proved the following theorem: *The necessary and sufficient condition that a given subgroup of a group gives rise to a multiply transitive representation of the group, or of one of its quotient group whose order exceeds two, is that every right co-set with respect to this subgroup has at least one operator in common with every left co-set with respect to the same subgroup.* This theorem may also be stated as follows: the necessary and sufficient condition that H gives rise to a multiply transitive group is that all the operators of G are included in the two sets H and HSH, S being any operator of G which is not also in H.

When the multipliers $S_2, S_3, \ldots, S_\rho$ in the right co-sets are the same as those in the left co-sets (this is possible for every subgroup of G) two co-sets are said to correspond when they have the same multipliers; that is HS_α and $S_\alpha H$ are two corresponding co-sets. It results from what precedes that this correspondence can be established in only one way when H is invariant under G and it can be established in $(\rho-1)!$ ways when H gives rise to a multiply transitive group. Conversely, when this correspondence can be established in only one way H must be invariant, and K must be multiply transitive whenever it can be established in $(\rho-1)!$ ways.

It should also be observed that the operators of each right co-set are evenly distributed among a certain number of left co-sets whenever they do not all occur in the same left co-set. Similarly the operators of each left co-set must be evenly distributed among the right co-sets. As the transitive constituents of K_1 are not necessarily of the same degrees it results that the operators of two right co-sets are not necessarily distributed among the same number of left co-sets, or vice versa. It may be observed that the method of dividing all the operators of a group into those of a subgroup and the corresponding co-sets was used by Abbati in 1802 and hence it is one of the oldest processes in group theory. This may add interest to the theorem given above in regard to the relation between a multiply transitive representation and the properties of the corresponding co-sets.

§ 2. *Transitive constituents of the subgroup composed of all the substitutions which do not involve a certain letter.*

Suppose that the operators of the right co-set HS_2 are found in the λ left co-sets $S_2H, S_3H, \ldots, S_{\lambda+1}H$. The totality of operators HS_2H must therefore give all the operators of these λ left co-set, each operator occurring as many times as there are common operators in H and $S_2^{-1}HS_2$. Hence λ is the index under H of the subgroup composed of these common operators. On the other hand, λ is the degree of the transitive constituent of K_1 which involves the letter replacing a in the substitution corresponding to S_2 in K. Hence *the necessary and sufficient condition that K_1 involves a transitive constituent of degree n_1 is that G involves a substitution which transforms H into a group which has a subgroup of index n_1 in common with H.* In particular, the necessary and sufficient condition that K_1 omits β of the letters contained in K is that H is invariant under a subgroup of G whose order is β times that of H; when $\beta = \rho$, K is regular and vice versa.

From the theorems proved in the preceding paragraph it is easy to deduce abstract group theory proofs for a number of theorems relating to simply transitive primitive groups. If K is such a group, K_1 is maximal, and if one of the transitive constituents in K_1 is of order p, p being a prime number, K_1 involves an invariant subgroup of index p, as well as a transitive constituent of degree p.

Hence its order is a power of p. As H and $S_2^{-1}HS_2$ have a subgroup of index p in common and as such a subgroup is always invariant in a group whose order is a power of p, it results that these common operators form an invariant subgroup of K. This is impossible unless the order of this common subgroup is unity and hence K, cannot involve a transitive constituent of order p unless the order of K_1 is p.[5]

When K_1 involves a transitive constituent of degree n_1, H and $S_2^{-1}HS_2$ have a subgroup of index n_1 in common and vice versa as was proved above. It is also known that G involves a multiple of n_1h operators which transform H into a group having exactly a subgroup of index n_1 in common with H. It is evident from the above that there are exactly n_1h such operators for every transitive constituent of degree n_1 in K_1. Hence we have the following theorem: *If G involves kn_1h operators which transform H into a group having exactly a subgroup of index n_1 in common with H then must K_1 have exactly k transitive constituents of degree n_1 and vice versa.* In particular, K is multiply transitive when K_1 is transitive and of degree $\rho-1$. Hence the necessary and sufficient condition that K is multiply transitive is that G contains an operator which transforms H into a group which has exactly a subgroup of index $g/h - 1$ in common with H, g and h being the orders of G and H respectively. This theorem gives meaning in certain cases to the theorem, if a subgroup H_1 of a given group G has exactly ρ operators in common with a conjugate of a subgroup H_2 of G, then the number of the operators of G which transform H_2 into subgroups having exactly ρ operators in common with H_1 is $kh_1h_2 \div \rho$, h_1 and h_2 being the orders of H_1 and H_2 respectively. The given theorem gives a meaning to k whenever H_1 and H_2 belong to the same system of conjugates.

From the main theorem of the preceding paragraph it is easy to obtain the degrees of all the systems of intransitivity of K_1. To obtain the orders of the transitive constituents of K_1 it is only necessary to observe that if $S_\alpha HS_\alpha^{-1}$ has a subgroup of index n_1 in common with H and if the largest invariant subgroup of H contained in this common subgroup is of index m_1 under H then the

[5] *Proceedings of the London Mathematical Society*, vol. 28 (1897), p. 536.

corresponding transitive constituent in K_1 is of order m_1 and of degree n_1. The fact that its order is m_1 results directly from the facts that the n_1 right co-sets which involve all the operators of HSH have the property that each of them is unchanged when multiplied on the right by any one of the operators of this invariant subgroup. Moreover, it is evident that the identity of each transitive constituent of K_1 must correspond to an invariant subgroup of K_1. Hence it results that *If* $H_1, H_2, \ldots, H_\lambda$ *be any complete set of conjugate maximal subgroups of* G *then each index under any one of these subgroups as regards the largest invariant subgroup which it has in common with any other is divisible by the same prime numbers for every possible pair in the set of conjugate subgroups.*

As a special case of the theorems proved in the preceding paragraph we have the following: The necessary and sufficient condition that K_1 is composed of simply isomorphic transitive constituents is that every invariant subgroup of H which occurs in one of its conjugates under G occurs also in all of these conjugates. This condition must clearly be fulfilled when K_1 is transitive; that is, in this case H cannot have an invariant subgroup in common with any one of its conjugates unless this subgroup is also invariant under G. This theorem exhibits an interesting abstract group property which corresponds to the property that K_1 is composed of simply isomorphic transitive constituents and with those mentioned above establishes more completely the principle of duality as regards substitution groups and abstract groups.

§ 3. *Transitive representation as regards right and left co-sets.*

Since both the right and the left co-sets of G are determined by the subgroup H each of these two categories of co-sets together with H forms a totality whose elements are permuted among themselves when the former are multiplied on the right and the latter on the left by operators of G. The ρ sets obtained by adding H to the right co-sets will be called the *augmented* right co-sets. Similarly we shall use the term augmented left co-sets for the ρ sets obtained by adding H to the left co-sets. It is known, and also evident, that the permutations among themselves obtained by multiplying the augmented right co-sets on the right successively by all the operators

of G constitute a substitution group K which is simply isomorphic to the quotient group of G with respect to the largest subgroup of H which is invariant under G.

To see very clearly the relation between G and K it is perhaps best to assume at first that they are simply isomorphic. We shall represent by K_1 the subgroup of G which corresponds to H in the simple isomorphism between G and K. Hence K_1 is also composed of all the substitutions of K which omit a given letter a, as was observed in the preceding section. As each of the co-sets is composed of all the substitutions of K which replace a by a particular letter we may name each of these co-sets by this particular letter. In particular, K_1 will be represented by a. If this is done it is evident that the permutations of the augmented co-sets due to multiplying all these co-sets on the right by the same substitution will be identical with this substitution. That is, the substitutions of K will only be repeated by the permutations of the augmented right co-sets when all of them are multiplied on the right by all the substitutions of K. That this arrangement was possible is a direct consequence of the manner in which K was constructed, the details which we gave are intended to exhibit more clearly how this may be done.

We proceed to consider the substitution group K' which corresponds to the permutations of the augmented left co-sets when these are multiplied successively on the left by all the substitutions of K, in order. We again suppose that K_1 corresponds to H and that it is composed of all the substitutions of K which omit a. The left co-sets are composed separately of all the substitutions of K which replace a particular letter by a. We shall name each of these co-sets by this particular letter and hence H will again be denoted by a. Multiplying each one of these augmented left co-sets on the left by the separate substitutions of K gives a permutation of these co-sets represented by the inverse of the multiplying substitution. Hence we again obtain a repetition of all the substitutions of K if we consider the permutations of the augmented left co-sets when these are multiplied on the left by all the substitutions of K in order.

From the preceding paragraphs it results that the right and left

augmented co-sets may be so named respectively that there results the same substitution group when the left augmented co-sets are multiplied on the left as when the right augmented co-sets are multiplied on the right. When H is invariant under G K is regular, and K and K'' are each composed of all the substitutions on these letters which are separately commutative with every substitution of the other, K'' being obtained by left-hand multiplication when the co-sets (which reduce to single operators in this case) are named the same as in the right co-set. As K'' reduces to K when these co-sets are named in the manner noted above it results from what has been proved that K and K'' are conjugate. When K is composed of substitutions of order two in addition to the identity, the two given methods of naming the co-sets will coincide and hence the given process also gives, as a special case, a proof of the theorem that every group in which all the substitutions besides the identity are of order 2 must be abelian. It should be added that the main results of this section are not new but the subject is so important that these details should be of some interest as they throw new light on the entire process.

UNIVERSITY OF ILLINOIS,
May, 1910.

SERPENTINES OF THE CENTRAL COAST RANGES OF CALIFORNIA.[1a]

(PLATES XXXIV AND XXXV.)

BY H. E. KRAMM.

COMMUNICATED BY PROF. J. C. BRANNER.

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INTRODUCTION.

It is the object of this paper to present a petrographical description of serpentines in the central coast ranges of California.

The areas under discussion are found in the region south from Clear Lake in Lake County to the New Almaden Mine in Santa Clara County, a distance of about 140 miles, and aggregates perhaps 300 square miles.

[1a] A thesis for the degree of A.M. presented to the Department of Geology of Stanford University, May, 1910.

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These serpentines were designated by G. F. Becker as being derived from sedimentary rocks, which he believed had obtained the magnesia necessary for their transformation into serpentine by a process of substitution.[1] Previous to his report which appeared in 1888 some Colusa County serpentines had been described by M. E. Wadsworth as lherzolite serpentines.[2] Others, the Mount Diablo,[3] Potrero,[4] Angel Island,[5] San Francisco Peninsula[6] and the Oak Hill[7] serpentines have since been shown to be derivatives of eruptives.

These latter areas aggregate perhaps ten to fifteen square miles which is, according to Becker, about one per cent. of the total serpentines in the coast ranges. Their investigation, aside from having demonstrated that the rock is derived from eruptives, has also shown interesting variations in the serpentine itself.

Taking this into consideration, a study of the remaining areas seemed desirable, even though such might not produce new and startling facts.

The accompanying map shows the distribution of the rock in the central coast ranges. Existing maps proved of valuable assistance in the field as well as in the preparation of the map. While some of the data for it were thus obtained, other data were obtained by the writer, who is aware that there may be serpentines especially in Napa, Marin and Solano counties which may have escaped his attention.

[1] G. F. Becker, "Quicksilver Deposits of the Pacific Coast," Monograph XIII, U. S. G. S., 120–128, Washington, 1888.

[2] M. E. Wadsworth., "Lithological Studies," *Mem. Mus. Comp. Zool. Harvard College,* 1884, 129–132.

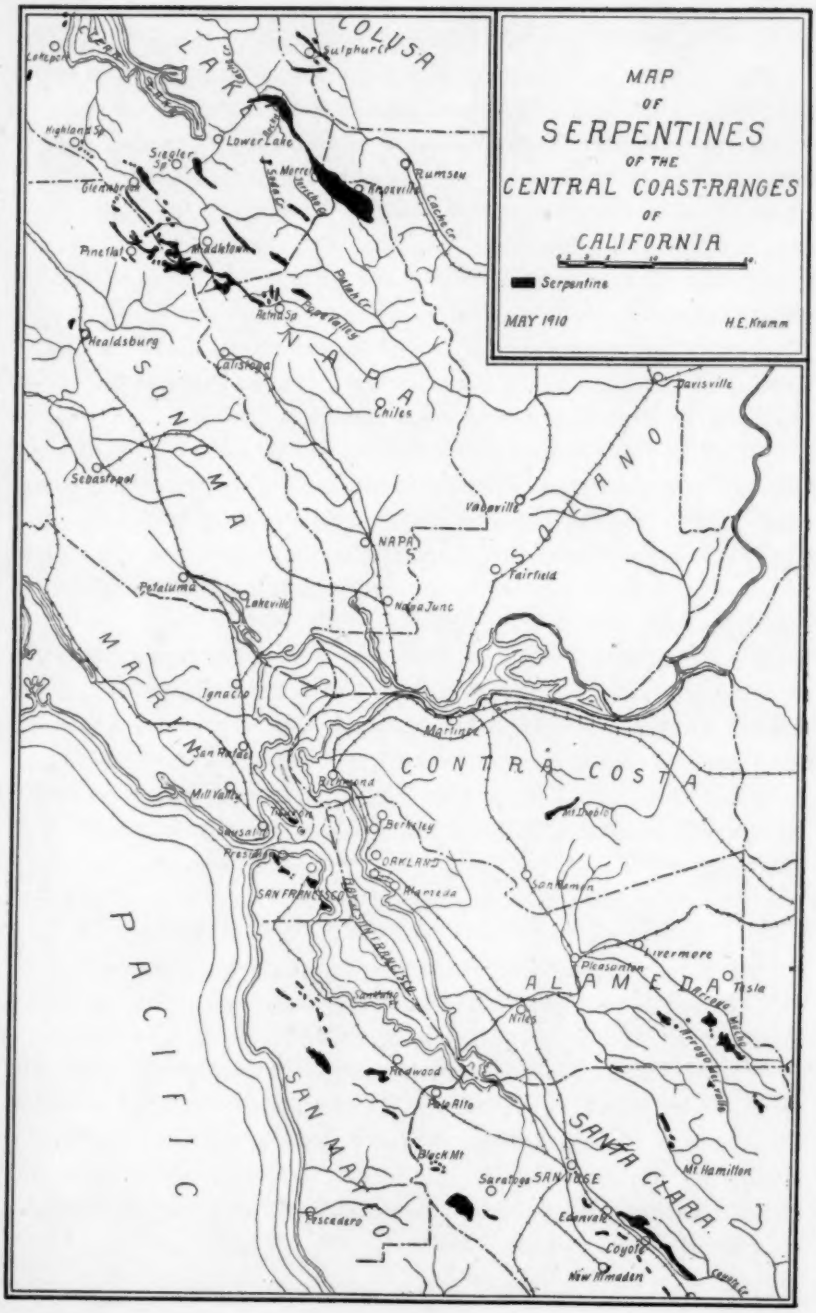
[3] H. W. Turner, "The Geology of Mount Diablo, California," *Bull. Geol Soc. Am.,* II., 388–391, 1891.

[4] C. Palache, "The Lherzolite Serpentines and Associated Rocks of the Potrero, San Francisco," *Bull. Geol. Dept., Univ. Cal.,* I., 164–169, 1894.

[5] F. L. Ransome, "The Geology of Angel Island," *Bull. Geol. Dept. Univ.* Cal., I., 219, 1894.

[6] A. C. Lawson, "Geology of the San Francisco Peninsula," 15th Annual Report U. S. G. S., 445, Washington, 1893–94.

[7] E. P. Carey and W. J. Miller, "The Crystalline Rocks of the Oak Hill Area near San José, Cal.," *Journal of Geol.,* XV., 160, 1907.


MAP
OF
SERPENTINES
OF THE
CENTRAL COAST RANGES
OF
CALIFORNIA
Serpentine
MAY 1910
H.E. Kramm
COLUSA
LAKE
NAPA
SONOMA
MARIN
CONTRA COSTA
ALAMEDA
SANTA CLARA
SAN MATEO
SOLANO
PACIFIC
Sulphurk
Lower Lake
Siegler Sp
Highland Sp
Glenbrook
Pine Flat
Middletown
Rumsey
Knoxville
Cache Cr
Putah Cr
Petrified Sp
Calistoga
Healdsburg
Sebastopol
Chiles
Vaca Valley
Davisville
NAPA
Fairfield
Petaluma
Lakeville
Napa Junc
Ignacio
Martinez
San Rafael
Mill Valley
Sausalito
Richmond
Berkeley
OAKLAND
Alameda
SAN FRANCISCO
Mt Diablo
San Ramon
Livermore
Pleasanton
Niles
Irvington
Redwood
Palo Alto
Mt Hamilton
Black Mt
Saratoga
SAN JOSE
Edenvale
Coyote
New Almaden
Pescadero

General Location of the Serpentines.

For the sake of description and convenience the areas have been divided into districts. These are named and situated as follows:

I. The Sulphur Creek district is about twenty miles east of Clear Lake. It is situated about the headwaters of the Sulphur Creek, a tributary to Cache Creek, and embraces the Lake and Colusa County dividing line.

II. The Knoxville and Clear Lake district comprises all those serpentine areas which are found about the point at which Lake, Yolo and Napa counties meet. It is limited in the north by Cache Creek and in the south by Putah Creek. It also includes the areas found in the immediate neighborhood of Clear Lake.

III. The Mayacmas district is bounded in the north by Putah Creek. It embraces the serpentines found along the Mayacamas range, which from Mount St. Helena extends to the northwestwards.

IV. The San Francisco district takes in all areas of serpentine found on the San Francisco peninsula, and areas in the vicinity of San Francisco.

V. The Coyote Creek and Black Mountain district comprises all serpentines which are found in the country drained by the Coyote Creek, south of San Jose, besides these the serpentines found in the Black Mountain region.

VI. The Mount Diablo and Mount Hamilton district includes all serpentine areas which are found in the country between these mountains.

I. The Sulphur Creek Serpentines.

The serpentines of this district form two belts, each one several miles in length, and in width varying from 100 feet to one half mile. Besides these, there are two smaller areas.

The first and most important belt is encountered about 100 yards west of the Wilbur Springs Hotel. From here it extends five miles in a northwest direction, forming the backbone of a ridge which stands out prominently above the surrounding country. To the south it extends a distance of one mile, and closely approaches the second belt of serpentine.

The second belt has an east-and-west trend, and follows for about three miles the ridge that forms the Colusa and Lake County dividing line, then extends one mile to the west.

Of the two smaller areas one is found 100 yards northwest of the Wilbur Spring Hotel, the other is best located by the Wideawake quicksilver mine. Both aggregate only a small fraction of a square mile, but the former has attained a certain local fame, due to the abruptness with which it terminates, exposing an almost perpendicular height of about 100 feet, which is known as the lovers' leap.

With the exception of the last the serpentine outcrops are very low. They seldom protrude more than a few feet above the surrounding soil, the removal of which keeps pace with the erosion of the rock. All stages of decomposition can be observed. Very fresh rock is found where Sulphur Creek cuts the first named belt of serpentine. It is exceedingly brittle, of a dark green color, massive, and shiny individuals of pyroxene give it a mottled appearance. As it weathers it assumes a brownish color, and finally gives rise to a brown soil.

Thin sections from fresh serpentine show a colorless mass with a slight green tinge with now and then patches of a more intense green, the whole somewhat pleochroic. Crossed nicols reveal serpentine to be the predominating mineral, with enstatite, diallage and olivine less abundant. Minor quantities of picotite, chromite and magnetite are present.

The microscopical investigation was supplemented by a chemical analysis made by the writer in the mineralogical laboratory of Stanford University, of fresh serpentine from the bed of Sulphur Creek, with the following results:

The analysis shows a very basic rock, and points towards a peridotite. It corroborates the microscopical investigation. Using the theoretical formula for serpentine the approximate ratio of serpentine to other minerals present can be calculated by assuming that all the water goes with the serpentine. The ratio thus obtained is four to one.

The above presented evidence shows that the parent rock was an eruptive, very basic, and contained the minerals which define a lherzolite. The serpentine is therefore a lherzolite serpentine.

ANALYSIS OF SERPENTINE, SULPHUR CREEK, COLUSA CO.
H. E. Kramm, analyst.

	Per Cent.
SiO_2	37.62
Al_2O_3	1.20
Fe_2O_3	8.60
FeO	2.15
MgO	37.59
CaO	2.49
Na_2O	.27
K_2O	trace
H_2O	10.46
Cr_2O_3	.36
TiO_2	trace
	100.74

While the foregoing only treats the massive facies of the serpentine it is of interest to study the other facies present. The rock as a whole shows an advanced state of decomposition. It is much shattered and slickensided, due no doubt to the increase of volume of the parent rock in the course of hydration into serpentine, and the resulting pressure. Angular fragments, bluish-green to brown in color, crumbling away under slight pressure often enclose rounded boulders of an apple green tough serpentine. These are traversed in all directions by numerous veins of chrysotile, reaching sometimes a thickness of two centimeters. The chrysotile being more resistant towards weathering stands out from the main bulk. This facies is especially prominent where the creek cuts the first belt of serpentine. A similar rock is found at the Potrero in San Francisco and has been described by C. Palache.[8]

The decomposition of the serpentine changes its structural features. The usually massive fresh rock often becomes granular. Numerous veinlets of black magnetite give it a banded appearance and a high specific gravity. Cavities form, which are colored white by magnesite or hydromagnesite. (See Plate XXXIV, Fig. 1.) At this stage the serpentine has more or less transformed into a silicious mass, which is tough, and not breaking exhibits the characteristic greasy luster of opal, while remnants of the serpentine are

[8] C. Palache, "The Lherzolite Serpentines and Associated Rocks of the Potrero, San Francisco," *Bull. Geol. Dept. Cal.*, I., 166, 1894.

still recognizable, bastite being the most resistant. The silicious substance assumes a red or yellow color upon weathering, due to the oxidation of iron compounds, and finally crumbles away. This feature of the rock is fully described by A. Knopf.[9]

The serpentine is associated with a coarse-grained somewhat metamorphosed sandstone, in which biotite is prominent and which in places assumes the character of a fine-grained conglomerate. To the south of the first belt where the Manzanita Mine is located shales are found. The sandstone, according to G. F. Becker, is of Knoxville age.[10] This he substantiates by the finding of impressions of *Aucella Piochii* in the metamorphosed rock close to the Manzanita Mine on Sulphur Creek. Although no direct contact was observed by the author, it being covered by soil and brush, the approximate contact is marked by a more intense degree of metamorphism of the sandstone. It is here exceedingly hard and responds to the blow of the hammer with a metallic ring. In the bed of Sulphur Creek was also seen serpentine which carried angular fragments of the sandstone.

The contact metamorphism is not accompanied by crystalline schists, but is such as would be caused by a strong thermal action.

II. The Knoxville and Clear Lake District Serpentines.

The Knoxville Serpentine.

The district as has been defined is the strip of country bounded in the north by Cache Creek and in the south by Putah Creek. Its principal body of serpentine which covers an area of approximately forty square miles is perhaps the largest found in the cntral coast ranges. A narrow strip a few hundred feet wide runs parallel to Perkins Creek, two miles south of it. Crossing Cache Creek it broadens out, capping the ridge that has its highest point a mile southwest of the Shamrock Mine. At this point the serpentine has a width of about one mile. Maintaining this width, it follows

[9] A. Knopf, "An Alteration of Coast Range Serpentine," *Bull. Dept. Geol. Univ. Cal.*, IV., 425, 1906.

[10] G. F. Becker, "Quicksilver Deposits of the Pacific Coast," Monograph XIII., U. S. G. S., 183, Washington, 1888.

Rocky Creek south to its headwaters, forming a series of low peaks to the east of the creek. Occasional outcrops from here have a northwest-southeast trend, establishing a connecting link with the main body of serpentine, which following the same general direction gradually expands to a width of four miles, passes to the south of Knoxville, and finally terminates about three miles southeast of Knoxville in a series of rugged outcrops.

The area as a whole presents a monotonous aspect. One sees a series of rocky ridges densely covered with brush and here and there a tree.

In the northwest, Rocky Creek cuts its way through the area and at places exposes steep walls of serpentine a hundred and more feet high, rising almost perpendicularly. The bed of the creek is strewn with big boulders which sometimes reach a diameter of ten feet. This is especially noticeable near the Shamrock Mine.

In the southwest Hunting Creek has cut a deep narrow canyon which gradually widens out towards the south, and into which enter a number of smaller canyons formed by tributaries. As at Rocky Creek the serpentine here is exposed presenting steep walls, and its débris covers the creek bed.

The headwaters of Davis Creek which drains to the north, and is a tributary to Cache Creek, have left their imprints upon the topography. Excellent opportunities for collecting fresh specimens are afforded by these drainage channels.

In many respects the serpentine resembles the one found at Sulphur Creek. It however presents a greater variety of colors. They vary with the degree of weathering the rock has undergone and the amount of iron it possesses. Upon fresh surfaces it is usually a dark green or almost black. The first indication of weathering is a yellow or a red color. Exposure to the atmosphere and the sun bleaches the serpentine and causes a decrease in hardness. A greenish-white slippery mass which resembles talc is the end product.

While here, as in the Sulphur Creek region, the shearing action is intense, and manifests itself in many slickensided fragments, the nodular variety of serpentine is not represented to any extent. This indicates a more homogeneous original mass.

Of the many hand specimens collected from this region one is of especial interest (Plate XXXIV, Fig. 2). It was taken from an outcrop on the western bank of Rocky Creek, and about one half mile south of the Shamrock Mine. It is a bastite pseudomorph after a pyroxenite and has beautifully retained its characteristic structure. The individual crystals are of a lighter green tint. The whole mass appears somewhat dull with now and then a glittering surface. The rock is massive, tough, due to the interlocking crystals and is easily scratched by a knife.

The microscope reveals that alteration has not been complete. Prismatic crystals of enstatite with prominent cleavage at right angles to the elongation of the fibers are still present. The slide shows bastite, some antigorite and a few minute veins of chrysotile.

Of interest are numerous transparent grains irregularly distributed with a tendency to concentrate along the bastite bands. They present a medium high relief and are isotropic. Sometimes these grains approach octagonal outline, but mostly they are of oval shape. Optically they behave like spinel, the index of refraction of which, being lower than that of methylene iodide, differentiates it from garnet. Plate XXXV, Fig. 3 gives an idea of the spinel.

The same mineral was found in a pseudomorph after a websterite from Mount Diablo, where it is of a secondary nature, since it was not observed in fresh rock. This similarity of condition makes it safe to assume that it is a secondary mineral here also.

The total quantity of this variety of serpentine is a small one. The outcrop is surrounded by the kind of serpentine common in this area, which is altered to a considerable extent.

The nature of the primary rock is indicated by a thin section made of fresh serpentine in which remnants of olivine, enstatite and diallage are found. Other minerals present are picotite, chromite and magnetite.

The predominating rock with which the serpentine is associated is a medium-grained grayish-yellow sandstone interbedded with shales. As one follows the road from Lower Lake to Knoxville and approaches the serpentine, one sees enormous thicknesses of it exposed. The dip is high, usually near 90 degrees. The angles are not constant. They vary considerably, sometimes within a few

hundred feet. It is possible to travel a short distance and measure any angle. The rock is compact, specked with grains of biotite and well consolidated.

Outcrops of what is evidently the same sandstone are found a few hundred yards northwest of Morrell within the serpentine mass. They resemble serpentine to such an extent that seen even from a short distance they are taken for it. They have the rugged appearance of serpentine outcrops and the same lighter tint green which it often assumes upon weathering. A close inspection reveals the grain of the sandstone, decided bedding planes, and a hardness which by far exceeds that of the serpentine. It also shows the intense degree of metamorphism. At places a slight schistosity has been developed. A thin section made of this rock contains the usual acid ground mass of a sandstone, a few flakes of biotite and considerable epidote.

Crystalline schists and boulders of metamorphic rock are found included in the serpentine on the crest of a ridge north of Knoxville. The serpentine is crushed to fine scaly masses resembling a shale.

About one half mile south of the Shamrock Mine a tributary to Rocky Creek cuts the sandstone which butts against the serpentine on the east of Rocky Creek. Narrow seams of interbedded shale which carry *Aucella Piochii* in abundance are exposed. Towards the serpentine the sandstone is strongly metamorphosed.

An actual contact of a shale with the serpentine is exposed by the Johnson shaft of the Knoxville Mine. The shale however does not seem to be much altered and it has not ben ascertained whether or not it contains fossils.

The mineralogical character of the serpentine combined with the above evidence demonstrates that it is derived from an eruptive rock which is intrusive into the Knoxville formation.

There are two smaller areas of serpentine in the vicinity of the Knoxville area. One is found about one mile south of Jericho Creek. It approaches Hunting Creek in the west. It extends in a northwestern direction approximately parallel to Putah Creek for four or five miles. Its width varies from a few hundred feet to one

half mile. Bordering it in the north is found a dike of olivine basalt, in the south the metamorphosed sandstone.

The other area is exposed by the road from Lower Lake to Knoxville about six miles from the former. It is represented only by a few outcrops with an east-and-west trend.

Both areas have very low outcrops and mineralogically correspond with the principal body of serpentine described in the preceding pages.

The Clear Lake Serpentines.

A small area of serpentine is found on the ridge north of Borax Lake, west of Clear Lake and south of the Sulphur Bank Mine. No specimens were obtained from this area. Becker[11] describes the serpentine, which seems to resemble closely the one met with at Knoxville and Sulphur Creek. Analyses are given of two varieties of serpentine, the first is of a black impure looking mass with phenocrysts, which are probably bastite, the second is of a purer variety. For comparison they are here appended.

ANALYSES OF SERPENTINE FROM NEAR BORAX LAKE, LAKE COUNTY.
Analyst not stated.

	I. Per Cent.	II. Per Cent.
SiO_2	39.64	41.86
Al_2O_3	1.30	.69
FeO	7.76	4.15
MgO	37.13	38.63
Cr_2O_3	.29	.24
NiO	.33	trace
MnO	.12	.20
H_2O	13.81	14.16
	100.38	99.93

It is seen that in chemical character the serpentine closely approaches that of Sulphur Creek. The total iron although given here as ferrous probably includes also iron in a ferric state.

Another serpentine area is located by Siegler Springs and Howard Springs about seven miles southwest of Lower Lake. It has a northwest-southeast trend. At Siegler Springs its width is ap-

[11] Monograph XIII., U. S. G. S., p. 111, 1888.

proximately one half mile. It widens out towards Howard Springs, where it has a width of about one mile. From here a series of outcrops point to the southeast and can be followed for about three miles.

The serpentine, being more resistant towards erosion than the associated sandstone, occupies an elevated position in places rising several hundred feet. It is fairly well preserved, of a dark green color, with coarse phenocrysts of bastite, and is exceedingly brittle. Thin sections show that the rock is almost wholly made up of serpentine. Of original constituents enstatite and chromite only are found, while the mesh structure due to olivine is very prominent. Its similarity to the Knoxville serpentine leaves no doubt as to its origin from a lherzolite.

The road from Kelseyville to Cloverdale past Elliott Springs cuts several areas of serpentine. The first one to the east of the road is one and a half miles east of Highland Springs, and its extent is one quarter square mile. The second and most important one is met 200 yards south of Fowler. The road cuts it and exposes a vertical wall of 50 feet of serpentine of a bluish green color. Slickensided fragments and an advanced state of decomposition are pronounced features. Fresher specimens show the porphyritic appearance caused by protruding foliated crystals of bastite. The area covers one half square mile.

Single outcrops are found a mile north of Elliott Springs, near Elliott Springs, and also three quarters of a mile south of it on the slope of the mountain ridge which divides Sonoma from Lake County. All of the serpentines are intrusive in sandstones. A feature of the contact is the occurrence of glaucophane and muscovite schists thus pointing towards rocks of Franciscan age. Microscopically the serpentines resemble those of Howard Spring.

Serpentine is also found west of Clear Lake and in close proximity to it. There are three small areas. The most northern one borders Clear Lake and is best reached by following the road from Lakeport to Upper Lake. It is five miles from the first named place. Another area is a few hundred yards south of Lakeport to the west of the road leading to Kelseyville. The third area is

found to the east of the road from Lakeport to Glenalpine about one mile from the latter place.

The serpentine of these areas occupies low dome-shaped hills, over which numerous boulders of the rock ranging in diameter from one to three feet are strewn. From dark green to greenish blue they show the typical lherzolite serpentine in all its stages of decomposition.

III. The Mayacmas District Serpentines.

A narrow strip of serpentine extends in a northwest direction for about twenty-four miles, following more or less closely the Mayacmas range. It is very irregular in shape.

Near Ætna Springs are found a number of small areas with low outcrops which seem to form a connecting link with the Pope Valley serpentine and the Mayacmas area. Beginning at the Ætna Mine a narrow belt can be traced to the northwest by a number of quicksilver mines, the Twin Peak, Corona, Mirabel and Great Western Mines which are situated on its contact. The outcrops are very low along this belt. The contact, which is with a sandstone in the north, is partly with a basalt, partly with a sandstone in the south. Brush and soil cover it and only occasional outcrops indicate the general direction of the serpentine. The width of the belt varies. At places it is a hundred feet wide, but never more than one half a mile. Several narrow bands branch off to the south approaching Mount St. Helena.

At the Great Western Mine the belt assumes greater dimensions. It becomes more than a mile wide and forms the crest of the Mayacmas range, which here has an altitude of 2,900 feet and gradually rises as Pine Mountain is approached to 3,500 feet. At Pine Mountain the Mayacmas range divides into three branches, all extending in a northwest direction. The most southern one consists of a series of ridges and peaks of which Geyser peak is best known. The Big Sulphur or Pluton Creek cuts a steep canyon on its northern flank, forming a dividing line with that range of which Mount Cobb is the highest point looming to a height of 4,500 feet into the skies. The range furthest north is not continuous with the Mayacmas range. Putah Creek cuts a deep canyon which isolates it. It reaches an

altitude of about 3,000 feet and Mount Harbin and Mount Hanna are its prominent peaks.

Half of a mile west of Pine Mountain the serpentine ceases to be a continuous area. Isolated outcrops are found in three directions which have the general trend of the branches of the Mayacmas range. They are along the southern flank of the southern range and a number of quicksilver mines indicate the general direction. From the road connecting these mines they are seen as rugged barren masses, prominent on account of the bluish green color and the dimensions of the outcrop. Float of actinolite schist is quite abundant, and glaucophane schist is seen in place.

Another series of outcrops follows the range north of the Big Sulphur or Pluton Creek south of Mount Cobb. They are found as far west as the headwaters of Squaw Creek.

Occasional areas are also found north of Cobb Mountain, having a general trend towards Pine Mountain. The largest of these is a few hundred yards west of Glenbrook Springs and covers perhaps one half of a square mile.

The serpentine as a whole along this belt differs from the previously described ones in that it is in a more advanced state of decomposition. Specimens even of moderate freshness could not be obtained. The nodular variety is prominent in the neighborhood of Ætna Springs but the nodules also, are well on the way towards decomposition.

Where the serpentine is not slickensided, a feature which is predominant, the structure is granular. Serpentine with this structure seems to be more resistant. The outcrops are higher and are more bold. Often they are protected by a layer of moss. If such an outcrop then has jointing in approximately parallel lines it resembles sandstone to such an extent that to differentiate it, it is necessary to break the rock.

All slides made from specimens along this belt show similar features. Antigorite more or less stained with oxide of iron still shows the structure due to its origin from olivine in some slides, while in others decomposition has erased all genetic indications and nothing but a homogeneous greenish mass remains. Enstatite is still observed in fresher specimens and is besides chromite the only

constituent of the original rock remaining behind. Diallage is not present, but since it gives rise to antigorite and seems to be more susceptible to decomposition than enstatite, it was probably also a constituent of the original rock. Traces of picotite with a broad surrounding mass of chromite are seen (Plate XXXV, Fig. 4), and veins of magnetite are in abundance. With an advance of decomposition the carbonates dolomite, calcite and magnesite appear. They have no crystalline form, but are either granules enclosed in serpentine or vein filling.

The serpentine found near Glenbrook Springs differs somewhat from the above in structure and appearance. It is massive, well preserved and slickensided fragments are rare. It appears to be porphyritic, due to a yellowish brown ground mass which is very uniform and dotted by numerous green phenocrysts of bastite standing out prominently. Thin sections show that this coloration is caused by an abundance of oxide of iron.

Analysis of Serpentine from Mayacmas Range.

H. E. Kramm, Analyst.

	Per Cent.
SiO_2	39.98
Al_2O_3	1.12
Fe_2O_3	13.19
FeO	1.05
MgO	30.49
CaO	.46
Na_2O	.28
K_2O	.25
H_2O	13.26
Cr_2O_3	trace
TiO_2	trace
	100.08

Serpentine is also found on the road from Middletown to Lower Lake, about two miles south of Guenoc. The area has a northwest-southeast trend, an average width of a quarter mile and a length of about five miles, forming a low ridge which rises not more than a few hundred feet above the surrounding country. The serpentine is well preserved, and its similarity to the Knoxville serpentine makes further comment unnecessary. Herewith is given an analysis of a Mayacmas range serpentine made by the writer. It was taken

near the Missouri Mine about six miles northwest of Pine Mountain and is fairly well preserved.

Serpentine is also found bordering Pope Valley. The extent of these areas however has not been determined. Specimens from these areas show a typical lherzolite serpentine.

IV. The San Francisco District Serpentines.

The San Francisco Peninsula Serpentines.

Serpentine is found in the vicinity of San Francisco and at San Francisco proper. According to Lawson[12] they are grouped into three linear tracts which traverse the peninsula of San Francisco in a northwest-southeast direction. The most northern one extends from Fort Point on the Golden Gate to Hunters Point on the Bay of San Francisco, a length of ten miles and with a maximum width of 1½ miles. It is probably a continuous belt although sand and alluvium cover portions of it and make it appear as four distinct areas. These areas have the character of laccolites or dikes which are intrusive into the Franciscan series of rocks.

The character of the serpentine has been in detail investigated by Palache.[13] It is represented in two facies which are named the slickensided and the massive facies. The slickensided is similar to the one at Sulphur Creek described by the writer. The massive facies is dark green in color, translucent on thin edges and has a splintery fracture. The parent rock is a lherzolite.

Analysis of Serpentine from Presidio, San Francisco.

J. D. Easter, Analyst.

	Per Cent.
SiO_2	39.60
Al_2O_3	1.94
FeO, MnO	8.45
MgO	36.90
Cr_2O_3	.20
H_2O	12.91
	100.00

FeO in this case probably also includes Fe_2O_3.

[12] A. C. Lawson, "Geology of the San Francisco Penninsula," 15th Annual Report U. S. G. S., 445, Washington, 1893.

[13] C. Palache, "The Lherzolite Serpentines and Associated Rocks of the Potrero, San Francisco," *Bull. Geol. Dept. Univ. Cal.*, I., 164–169, 1894.

An analysis of a Presidio serpentine made by Easter is given on account of the similarity with the one made by the writer on Sulphur Creek serpentine.

The second belt of serpentine occupies the southeastern portion of Buri-Buri ridge from San Andreas Lake to San Mateo Creek, and nearly the whole of Las Pulgas ridge, with a total length of 11½ miles and a maximum width of over one mile.

The third belt consists of a linear group of dike-like masses distributed along San Mateo Canyon between Sayer and Cahill ridges, on the pass between Cahill and Fifield ridges, and thence obliquely along Fifield ridge and across San Pedro Valley nearly to the ocean. The linear extent is six miles. There are also some few minor outcrops not referable to these belts.

All these serpentines exhibit similar features to those which Palache designated as lherzolite serpentine.

The Angel Island Serpentine.

Angel Island is situated in the bay of San Francisco 3½ miles north of the city of San Francisco. The geology of the island has been described by Ransome. Serpentine is found along the western portion of the island as a large dike having a maximum width of 500 feet. Intrusive into the San Francisco sandstone, it has metamorphosed it to some extent. The two facies, the slickensided and the massive are present. The slickensided differs from the one found at the Potrero in that the nodules are not as large and the matrix is less broken.

ANALYSIS OF SERPENTINE FROM ANGEL ISLAND.

F. L. Ransome, Analyst.

	Per Cent.
SiO_2	42.06
Al_2O_3, Fe_2O_3	2.72
FeO	2.88
MgO	39.53
H_2O	12.04
	99.23

The massive facies is of unusual interest. It is made up of interlocking crystals of diallage with small amounts of magnetite and

possibly some chromite. It would therefore correspond to a diallagite.

An analysis made by Ransome upon serpentine taken from a nodule of the slickensided facies is given above:

The Tiburon Peninsula Serpentine.

Although a narrow channel of the San Francisco Bay separates it the Angel Island serpentine is probably continuous with the one which is found north of it at the extreme tip of the Tiburon peninsula. It covers an area of perhaps one square mile. The road following the western shore line exposes the slickensided facies about 100 yards east of the ferry station.

The serpentine is much decomposed but the nodules, which often are several feet in diameter show fairly fresh serpentine which is very brittle. Vein serpentine is common.

The outcrops of this part of the area are small. The soil is of a reddish color and vegetation is scant. The crest of the ridge presents different features.

Outcrops reach a height of about 15 feet and consist of the siliceous mass, to which serpentine gives rise, and which is known in the coast ranges as the quicksilver rock. From a distance they resemble a conglomerate, close inspection however reveals the honeycombed tough silicious mass with magnesite stains here and there. Remnants of the serpentine can still be observed. The whole presents a rugged appearance. Magnesite float is abundant.

Slides of the fresh serpentine show the following minerals bronzite, diallage chromite and magnetite. The mesh structure due to olivine is prominent.

V. The Coyote Creek and Black Mountain Serpentine.

Serpentine is also found on what is known as the Los Lagrinas ridge a part of the Mount Hamilton range south of San Jose east of the Coyote Creek in Santa Clara County. The ridge consists of a series of kidney-shaped hills bordering the valley in the east, and reaching a maximum elevation of 300–400 feet above the valley level. About four miles south of Coyote station is the extreme southern end of the serpentine area, which covering the western slope of the ridge extends north to within one half mile of Edenvale.

What is probably an extension of this area, separated by alluvium is found on the opposite side of Santa Clara Valley. It follows a group of well-rounded crests which in a wide circular sweep reach to within four miles of San Jose. This area is known as the "Oak-hill," and its crystalline rocks are described by Carey and Miller.[14]

The serpentine here is of a dike-like nature intrusive into radiolarian charts and sandstones of Franciscan age. It is variable in character. A massive phase shows glistening phenocrysts of diallage in a dark-green ground mass of serpentine which grades into a diallagite. The structural and mineralogical composition of the serpentine indicates that it is derived from a peridotite containing olivine, diallage and magnetite, with enstatite but sparingly present.

Associated with the massive green serpentine, which is predominant, is found the slickensided facies and the "mottled" serpentine. The latter consists of the green serpentine to which white colored spots varying in size to a diameter of two inches give a mottled appearance. The white substance may possibly be magnesium silicate. A partial analysis of massive conchoidal serpentine is here appended. Plate XXXV, Fig. 5 represents a phase of the mottled serpentine.

Of much interest is the associated olivine-gabbro which on one hand passes into peridotite and pyroxenite, and on the other into hypersthene gabbro and norite. An analysis of what may be considered a pyroxenite-peridotite consisting principally of diallage with small quantities of olivine partly transformed into serpentine, and some magnetite was made by the writer and is given below.

The serpentine of the main area which follows the Los Lagranas ridge does not differ from the one above described. It is intrusive into Franciscan cherts and sandstone. The area is almost destitute of soil and the barren slopes are strewn with boulders of the dark green rock. The outcrops are low and seldom protrude more than three feet above the surrounding soil. The massive facies is predominant. A feature is the abundance of magnesite which is found as float, and also in veins of considerable size.

Mineralogically the serpentine is a lherzolite serpentine. The mass as a whole appears to be uniform, but variations occur. A

[14] E. P. Carey and W. J. Miller, "The Crystalline Rocks of the Oak-Hill Area near San José, Cal.," *Jour. of Geol.*, XV., 160, 1907.

small lenticular body of pyroxenite is found about one quarter mile southeast of Coyote station. It is made up entirely of enstatite which is unaltered, and an analysis of which by the author is here given.

ANALYSES.

	Serpentine.	*Pyroxenite-peridotite.*	*Enstatite-pyroxenite.*
	I. Per Cent.	II. Per Cent.	III. Per Cent.
SiO_2	37.71	42.76	56.98
Al_2O_3	1.81	5.71	1.73
Fe_2O_3	10.47	3.16	4.04
FeO		3.30	4.18
MgO	35.60	27.11	27.40
CaO	——	10.03	3.26
Na_2O	——	2.24	.59
K_2O	——	.49	.35
H_2O	——	4.85	2.04
Cr_2O_3	——	.22	.09
TiO_2	.09	.17	none
	85.68	100.04	100.66

I. Serpentine of the Oakhill area by U. S. G. S. Analyst not stated.
II. Pyroxenite-peridotite of Oakhill area. H. E. Kramm, analyst.
III. Enstatite-pyroxenite from near Coyote. H. E. Kramm, analyst.

South of the Oak-Hill area on the west side of Santa Clara valley, opposite the Coyote area, and having an approximately parallel trend with it, are several isolated areas of serpentine. The most northern one terminates on the road leading from San Jose to the New Almaden Quicksilver Mine. The most southern one is found about two miles northwest of Morganhill. A small area is also found near New Almaden.

The serpentine in general resembles that of the Coyote area, but shows a somewhat greater degree of decomposition.

About three miles southwest of Redwood in San Mateo County is a considerable area of serpentine. Its maximum width is somewhat over a mile, its linear extent four miles with a trend northwest-southeast.

Smaller areas are also found at the following places: one east of Searsville Lake about six miles west of Palo Alto, several south of

Black Mountain and one about four miles south of Saratoga. All of these are mapped in the Santa Cruz folio of the U. S. G. S.

Small pyroxenite bodies which consist of diallage are frequent in the Black Mountain areas. A feature of the Redwood area is tremolite secondary after serpentine, and talc after tremolite.

The similarity of the serpentine itself to that of the Coyote area makes further comment unnecessary.

VI. The Mount Diablo and Mount Hamilton Serpentines.

A lherzolite serpentine and a websterite are found at Mount Diablo in Contra Costa County. According to H. W. Turner[15] the area as a whole is dike-like, its length about five miles and its average width less than one half mile. The peridotite has largely been converted into serpentine, but specimens are still found which contain olivine, enstatite and diallage.

The pyroxenite is made up of bronzite and diallage, and is most prominent on the southwestern part of the area, occupying approximately one quarter of a square mile, but is also found at various other parts of the area.

The dike nature of the serpentine is best shown where the Arroyo del Cerro and its branches cut across the area east of the western fork of Pine Creek. The serpentine here varies in width from a few feet to 150 feet, and is enclosed in dark calcareous shales containing at several points near the serpentine "*Aucella Piochi*," with a strike and a dip about that of the shales which enclose it.

North of the serpentine area is found a diabase and the Knoxville sandstone, to the south it is bordered by metamorphosed sandstones.

A gabbro crops out north of the point where the serpentine dike crosses Bagley Creek. Between this gabbro and the serpentine lies like a body of *Aucella*-bearing shale, and up to present time no genetic connection between the two has been demonstrated.

The following analyses are given:

[15] H. W. Turner, "The Geology of Mount Diablo," *Bull. Geol. Soc. Am.*, II., 383, 1891.

ANALYSES OF SERPENTINES, MOUNT DIABLO.

	I.	II.	III.	IV.
SiO_2	53.25	36.57	40.50	41.52
P_2O_5	——	——	trace	——
Cr_2O_3	.54	.33	.41	——
Al_2O_3	2.80	.95	.78	1.57
Fe_2O_3	.69	7.29	4.01	3.50
FeO	5.93	.37	2.04	1.07
NiO	.07	.31	.11	——
MnO	.09	.10	.13	.29
CaO	16.22	.14	.39	.44
MgO	19.91	40.27	37.43	36.84
Na_2O	.19	.31	.28	——
K_2O	trace	trace	.16	——
H_2O at 105° C.	.05	.94	2.81	3.32
H_2O above 105° C.	.24	12.43	10.94	12.51
	99.98	100.01	99.99	101.06

I. Fresh pyroxenite with some olivine. W. H. Melville, analyst.
II. Bastite with fine seams of chrysotile. W. H. Melville, analyst.
III. Serpentine. W. H. Melville, analyst.
IV. Serpentine weathered interwoven with quartz and calcite. W. H. Melville, analyst.

Areas of considerable extent are found about fifteen miles southeast of Livermore to the west of the Arroyo Mocho in Contra Costa County, a few miles north of the Santa Clara and Contra Costa dividing line.

Other areas are to the west of the Arroyo del Valle to the south of Livermore in Contra Costa County, and in Santa Clara County. Still others are about six miles to the northwest of Mount Hamilton in Santa Clara County.

The location of these areas is best shown by the accompanying map.

These areas were not visited by the writer, but specimens of the serpentine are in the Stanford University collection.

Some of these are altered to the greenish-yellow slippery mass in which all genetic indications are obliterated; others exhibit the characteristics of a lherzolite serpentine. The presence of lenticular bodies of pyroxenites is indicated by specimens of diallagite and enstatite-pyroxenite which come from the serpentine areas northwest of Mount Hamilton.

Age of the Serpentines.

The similarity mineralogically and chemically of the serpentines makes it reasonable to suppose that the intrusion of its parent rock took place simultaneously throughout the coast ranges of California.

In the preceding pages, under areal description, it has been shown that in the Sulphur Creek and Knoxville districts, beds carrying *Aucella Piochii* are strongly metamorphosed by serpentine intrusion. The evidence points to a time of intrusion following the deposition of the Knoxville beds. This agrees with evidence obtained by H. W. Turner at Mount Diablo and with that of Fairbanks.[16]

Fairbanks reports Knoxville beds in which he found *Aucella Piochii* to be upturned and broken by serpentine masses. He puts on record other instances showing a shattering and metamorphosing of the Knoxville sandstone by the serpentine, and speaks of the finding of fragments of Knoxville shale in the serpentine and of serpentine in the Knoxville shale and sandstone. It is his opinion that the intrusion of the peridotite masses was at least partly responsible for the unconformity between the Chico and Knoxville beds.

The serpentines of the southern areas under discussion are usually associated with the Franciscan series of rocks, cherts and sandstones. Evidence which points to the time of intrusion of these dikes has to the writer's knowledge not been found up to the present time. This is to some extent caused by the lack of the Knoxville formation where the serpentine occurs.

Quicksilver in Connection with the Serpentine.

It is hardly possible to discuss the serpentines of the Coast Ranges without also bringing in quicksilver, and the relation which exists between its deposits and the serpentine.

The well known name "quicksilver rock" implies that decomposition product of the serpentine, which is a mixture of carbonates, compounds of iron and the three forms of silica quartz, chalcedony and opal. This rock occurs as dike-like masses in the body of the

[16] *American Geologist*, IX., 161–166, 1892.

serpentine itself, but is most common on contacts with the surrounding country rock, shale or sandstone.

The quicksilver is found filling existing pores, cracks and fissures of this rock. A few cases are known in which the ore is found in sandstone, which however is always in close proximity of serpentine bodies.

The principal ore is cinnabar. Mercury in a free state, metacinnabarite, and calomel are of less importance. The most common associates are marcasite, pyrite and chalcopyrite.

Under high temperature and pressure, in the presence of sulphohydrates and carbonates of the alkalies, mercury is in solution as the soluble salt $HgS + 4Na_2S$. Release of pressure, cooling especially in the presence of ammonia, dilution of the mineral-bearing solution, excess of hydrogen sulphide and the presence of bituminous substances are all factors which enter into the precipitation of the ore, bituminous matter leading towards a total reduction.

The intrusion of the peridotite masses in shattering the country rock provided channels through which the mineral-bearing waters circulated. These waters not only deposited the ore, but it is reasonable to suppose, that they were also to some extent instrumental in the decomposition of the serpentine. That conditions in this cherty decomposition product were exceptionally favorable for the deposition of the ore is substantiated by the fact that to the writer's knowledge cinnabar has never been found in the serpentine itself, nor is it found to any extent in the country rock. The few cases known in which the ore is found in sandstone show the sandstone to be of porous nature and as has been said located in the neighborhood of serpentine dikes.

As to the source of the quicksilver, Dr. Becker[17] suggests the base granite which underlies all sedimentary rocks in the Coast ranges.

Mineralogy of the Serpentines.

Primary Minerals.

The primary rock, as has been shown, with the exception of lenticular bodies of pyroxenites, is badly altered. Primary minerals

[17] G. F. Becker, "Quicksilver Deposits of the Pacific Coast," Monograph XIII., U. S. G. S., 449, Washington, 1888.

named in the foregoing are olivine, enstatite, bronzite, diallage, picotite and chromite.

Olivine is present only in the freshest variety of the rock and is even there not discernible in the hand specimen. Under the microscope it shows high relief, and is colorless. Cleavage cracks traverse it, which are often at rectangular position to each other and are usually filled with black opaque masses of magnetite. Crossed nicols show that in these cleavage cracks serpentinization has taken place and given rise to the mesh structure with small rounded fragments of the olivine occupying the central part of a mesh. A number of these rounded fragments usually extinguish together and thus indicate the size of the original crystal. Its lack of cleavage, its high relief and its bright interference colors distinguish it from the pyroxenes.

Enstatite is seen in the hand specimen as coarse prismatic crystals of a dark green color and with shiny cleavage surfaces which are parallel to the longer axis. Bastite is a pseudomorph after it, but can be recognized from it in that the crystals are easily scratched by a knife and are of a lighter green color. Under the microscope enstatite is seen in coarse platy crystals with a medium relief and a slight pleochroism from colorless to a light green. The cleavage is prominent. When basal sections are present, they sometimes present a dim prismatic cleavage.

Interference colors are of the first order, usually a bright yellow, the extinction is parallel and the slower ray is parallel to the elongation of the crystal. Plates parallel to the principal cleavage do not give an interference figure, which distinguishes it from bastite. Intergrowths with diallage are frequently observed.

Diallage is not quite as abundantly represented as enstatite. Under the microscope crystals of irregular outline are seen which resemble enstatite in cleavage lines and pleochroism. Crossed nicols however reveal bright interference colors, red and blue of the second order, and an oblique extinction. The maximum angle made with the principal cleavage was found to be 42 degrees. The slow ray is parallel to the elongation of the crystals. Besides the perfect (100) pinacoidal cleavage a well developed prismatic cleavage is seen in basal sections. Of enstatite and diallage the former appears to be

more resistant towards serpentinization. Partially altered fragments of it were even found in nearly decomposed serpentine.

Bronzite does not differ much from enstatite. Due to its higher iron content it has higher interference colors, red of the first order to blue of the second order, and is as a rule pleochroic from colorless to a bright yellowish-green.

Of the minor constituents *picotite* is probably the most interesting. Its grains are of considerable size and irregular in outline. They were always found to be surrounded by black opaque masses resembling either chromite or magnetite which also fill numerous cracks traversing the crystal in all directions. (See Plate XXXV, Fig. 4.) It is of a coffee-brown color, has a high relief and is isotropic.

It was possible to isolate some of these crystals by digesting with hydrochloric acid and passing the residue through Thoulet solution, then separating the picotite by hand. The crystals were .5 mm. in diameter, glassy and hard enough to scratch quartz.

The black coating was stripped off and subjected to the action of a magnet. It was not magnetic and gave chromium reactions before the blowpipe. It is therefore chromite.

A series of slides made of specimens of serpentine varying in degree of decomposition revealed interesting facts. As the decomposition advances the outer opaque covering increases in size while the picotite decreases. In a fairly decomposed serpentine the picotite was still visible as a dot. In a much decomposed specimen, picotite disappears and only the irregular masses of chromite remain. It seems therefore that chromite is secondary after picotite.

Chromite itself was found as a primary constituent. It differs from that considered as secondary in that the masses assume a more geometrical outline. They are usually opaque, sometimes slightly translucent with a reddish brown tint.

Considerable quantities of chromite are known to occur in connection with the serpentine, but are not utilized commercially at the present time. Dr. Becker mentions chromic iron as occurring not far from the Royal claim near Knoxville. It is of nodular form in a seam which has been exposed by the weathering of the serpentine. The writer has not been able to locate this.

Another noteworthy place where chromite is found in quantities is at Cedar Mountain in Alameda County. An analysis of chromite from this locality corresponds closely with that of a mineral intermediate between picotite and chromite from a dunite from Dun Mountains in New Zealand, which for comparison is appended.

	I.	II.
SiO_2	none	——
Al_2O_3	18.79	12.13
FeO	16.99	18.01
CaO	trace	——
MgO	8.41	14.08
Cr_2O_3	55.74	56.54
NiO, CaO	trace	trace
MnO	trace	0.46
H_2O	.09	——
	99.82	101.22

I. Chromite from Cedar Mountain. H. E. Kramm, analyst.

The mineral was purified by powdering it and passing through Thoulet solution. All iron was determined in the ferric state and calculated to ferrous iron. There was no doubt ferric iron present, but the amount could not be determined on account of the difficulty of getting chromite into solution.

II. Chromite-Picotite from New Zealand. Mineralogy, 6th ed. Dana, p. 228. Analyst T. Petersen.

Secondary Minerals.

The course of hydration and subsequent decomposition of the serpentine necessitates a change of molecular arrangement, and gives rise to a number of secondary minerals. According to Tschermak the conversion of olivine gives rise to serpentine, magnesite, limonite and silica. It seems very probable that the excess of magnesia will combine with free silica to form secondary serpentine. This is substantiated by the fact that fissures in the rock are invariaby filled with chrysotile.

Decomposition and the action of ground waters assist in the development of another series of minerals which are probably oxide of iron, magnetite, hydromagnesite and vein serpentine. It is reasonable that this vein serpentine is not necessarily confined to the serpentine body itself, but may find its way into the surrounding country rock, where under favorable conditions it is deposited.

This would explain the occurrence of serpentine veins in sandstones, a feature observed in the Coast Ranges and construed by Dr. Becker[18] as showing the conversion of the sandstone into serpentine.

While nearly all of the secondary minerals can be found in every serpentine locality in minor quantities, local conditions favor the accumulation of some few. Of minerals which are of a secondary nature serpentine itself is the most important. It is represented by its two varieties, antigorite and chrysotile.

The antigorite shows under crossed nicols as an aggregate of irregularly distributed minute bands and scales which have low interference colors, usually gray with a bluish tint. Due to the irregularity of distribution, extinction is compensatory.

Bastite is a variety of antigorite and is microscopically prominent in coarse prismatic phenocrysts, pseudomorphous after enstatite or bronzite. It has a prominent pinacoidal (100) cleavage and is distinguished from the pyroxenes in that it is soft and is readily scratched by a knife.

Under the microscope these pseudomorphs are irregular in outline, and consist of coarse bands of serpentine in parallel arrangement. A cross fracture is frequently observed, often at right angles to the fibers, but it may have any angle. The whole is somewhat pleochroic from colorless to light green. Extinction is parallel to the lines of prominent cleavage and the slow ray is parallel to the elongation. When alteration has been complete, the characteristic low bluish-tint interference colors of antigorite are exhibited. Using thin uniform sections these colors are raised as the degree of alteration becomes less and approach those of enstatite or bronzite. Thin cleavage plates give an interference figure.

The chrysotile consists of an aggregate of parallel fibers filling the numerous seams which traverse the rock in all directions. It has parallel extinction, the parallel position of the fibers and the bright interference colors, usually red or blue of the second order, make it easily distinguishable. Microscopically it is prominent as silky veins which often reach considerable thickness, and are the well-known serpentine asbestos.

[18] Ibid., p. 277.

Of the different types of structure, the mesh and the bastitic structure are invariably found. The former points towards an origin from olivine and fresh specimens often show remnants of this mineral in the center of the mesh. It consists of bands of serpentine which intersect irregularly, quite often in rectangular position to each other, surrounding aggregates of filled serpentine.

The bastitic structure is described under bastite, and needs no further comment.

No characteristic grate structure was observed. It is true, now and then a suggestion of it is seen.

Magnetite was never observed in fresh specimens of the rock but it is pronounced when the rock is altered. It then occupies cracks and seams in opaque irregular masses. Chemical and magnetic properties distinguish it from chromite. Large masses in connection with the serpentine are to the writer's knowledge not known in the Coast Ranges of California.

Magnesite is abundantly found as float and in veins of various sizes. It is usually massive, fine-grained, of a beautiful white color and with a conchoidal fracture. Besides being formed in the process of hydration of the primary minerals which give rise to serpentine, it is probably also produced when the serpentine breaks down.

The following analyses given by F. L. Hess[19] show the chemical character of the magnesite.

ANALYSES OF MAGNESITE.

	I.	II	III.
SiO_2	2.15	.30	49.85
Al_2O_3	1.22	.16	3.45
Fe_2O_3	1.16	.38	.18
CaO	5.28	1.34	.48
MgO	41.01	45.86	21.53
CO_2	48.72	51.80	23.96
	99.54	99.74	99.45

I. Magnesite from Chiles Valley, Napa County. P. H. Bates, analyst.

II. Magnesite from W. W. Burnett's ranch, Coyote, Santa Clara County. A. J. Peters, analyst.

III. Magnesite from near Morgan Hill, Santa Clara County. A. J. Peters, analyst.

[19] F. L. Hess, "The Magnesite Deposits of California," Bull. 355, U. S. G. S., Washington, 1908.

Tremolite was found at two places in connection with the serpentines in the neighborhood of the Culverbear group of quicksilver mines in Sonoma County and at the Redwood area of serpentine in San Mateo County. Small lenticular bodies are imbedded in the serpentine. More often they are found as float. They reach a diameter of four to five inches, are usually coated with iron stain, and are exceedingly tough. The mass has a somewhat schistose structure and when broken shows needle-like white crystals with a silky luster.

The microscope shows an interwoven mass of slender crystals. Some few are of stocky habit but with no definite shape. A cleavage parallel to the elongation and a cross fracture is present but not pronounced. The extinction is parallel in some sections, in others it varies. The maximum angle measures about 22 degrees. The slower ray is parallel to the elongation of the crystal and sections with parallel extinction show the emergence of an optical axis. The trace of the optical plane lies parallel to the cleavage. Sections cutting at right angles the plane of schistosity show a characteristic amphibole cross section with a pronounced prismatic cleavage of about 124 degrees.

Inclusions of a dark green mass of antigorite are frequent. The alteration of it into tremolite is plainly visible. It begins first on edges. Bunches of needle-like crystals are tangent to the more or less oval-shaped body. Their higher interference colors contrast sharply with the low birefringence of the antigorite.

The serpentine is dotted with specks of a brighter color. Under a high-power objective they resolve themselves into radiating bundls of fibers of tremolite. The process of alteration is therefore not confined to the boundaries of the mass but is also an internal one.

Tremolite was also observed in a section from a pseudomorph after a websterite from Mount Diablo.

Talc is very rarely found in connection with the serpentines. At the Redwood area it was found in place secondary after tremolite.

Hydromagnesite.—This mineral is a product of decomposition of the serpentine. Local conditions seem to influence its formation, as it is more abundant in some localities than in others. In the Sulphur Creek areas it is abundant.

It occurs in white chalk-like masses to which green inclusions of serpentine give a mottled appearance and which readily crumble away under slightest pressure. The ratio of serpentine to hydromagnesite is approximately as one is to two. An analysis of the purest sample gave results as follows:

ANALYSIS OF HYDROMAGNESITE.

H. E. Kramm, analyst.

SiO_2	9.37
Fe_2O_3, Al_2O_3	trace
CaO	2.46
MgO	39.25
CO_2	29.45
H_2O	18.74
	99.27

Crystals of hydromagnesite are found near Cedar Mountain in Alameda County.

Calcite occurs as veins in the serpentine and is a prominent constituent of the silicious mass to which serpentine gives rise. It is also found closely associated with the serpentine in what is known as ophicalcite. Specimens of ophicalcite which are a mixture of about one half calcite and one half serpentine were found at the Mirabel Quicksilver Mine in Lake County and at New Almaden in Santa Clara County.

Dolomite has an occurrence similar to that of calcite.

Aragonite is found in the neighborhood of Pine Mountain. At the Helen quicksilver mine in Sonoma County it occurs as needle-like crystals and fibrous crusts.

Epsomite. This mineral is found lining the shaft and drifts in the Knoxville Mine. Hair like crystals, snow white in color, somewhat brittle, with a silky luster often reach a length of a foot or more.

Melanterite is usually found as greenish-white hair-like crystals reaching a length of several inches, lining shafts and drifts in quicksilver mines. In the Knoxville mine it also occurs in stalactitic masses of a pale green color, which seem to melt in their own water of crystallization. On exposure to light it becomes dry, assumes a yellowish-green color and changes into copiapite.

Copiapite is less abundant than melanterite, the oxidation of which gives rise to it.

Redingtonite was first found in the Redington Mine at Knoxville and described by Dr. Becker.

Knoxvillite, according to Dana, occurs with redingtonite at Knoxville.

Limonite and hematite are products of decomposition of the serpentines and impart the red color to the soil derived from it. Commercially they are not important on account of impurity.

Conclusions.

In the preceding pages the following facts are demonstrated:

(A) The serpentines are derived from basic eruptive rocks.

For this speaks the irregularity of the serpentine bodies, which is a typical character of eruptive rocks. A glance upon the map also shows that, with the exception of the Mount Diablo serpentine, the areas have an approximately northwest-southeast trend, which corresponds to lines of structural weakness in the Coast Ranges.

Furthermore, the serpentine contains olivine and chromite. The first, with the exception of altered magnesian limestones, is found only in eruptive rocks.

The second has, to the writer's knowledge, never been found in serpentine derived from sedimentaries.

The chemical composition of the serpentine shows it to be related to peridotites.

Pseudomorphs after pyroxenites are not very well possible in serpentine derived from sedimentaries.

(B) This eruptive rock was fairly uniform and its time of intrusion falls in a period which followed the deposition of the Knoxville beds.

The uniformity is demonstrated by the analyses of the rock which show it to be of a basic nature.

The mineralogical investigation shows it to be a lherzolite, and the serpentine derived from it a lherzolite serpentine.

However, variations in this rock occur which are represented by lenticular bodies of pyroxenites which are usually of small dimen-

sions, but sometimes reach considerable size as in the case of the Mount Diablo pyroxenite.

The age of the serpentine is established by field evidence which agrees with that of Turner and Fairbanks and makes the serpentine post-Knoxville.

(C) Other facts which are of petrological interest are:

The lherzolite is in an advanced state of decomposition.

The freshest specimen found contained only about twenty per cent. of the original constituents of the rock.

Olivine readily undergoes decomposition. Enstatite and diallage are more resistant, and the latter seems to be more susceptible towards serpentinization than the former.

Picotite is quite abundant in fresh specimens of the northern areas and appears to give rise to chromite.

Secondary minerals besides the usual products of decomposition are spinel, tremolite and talc.

In closing the writer wishes to express his obligation to Professor A. F. Rogers, of Stanford University, under whose guidance and advice this paper was prepared.

TABLE OF ANALYSES.

Serpentines.

	I.	II.	III.	IV.
SiO_2	36.57	37.62	37.71	39.60
Al_2O_3	.95	1.20	1.81	1.94
Fe_2O_3	7.29	8.60	10.47	——
FeO	.37	2.15		
MgO	40.27	37.59	35.60	36.90
CaO	.14	2.49	——	——
Na_2O	.31	.27	——	——
K_2O	trace	trace	——	——
H_2O	13.37	10.46	——	12.91
MnO	.10	——	——	——
Cr_2O_3	.33	.36	——	.20
TiO_2	——	trace	.09	——
NiO	.31	——	——	——
	100.01	100.74	85.68	100.00

I. Bastite with fine seams of chrysotile from Mount Diablo. W. H. Melville, analyst.

II. Serpentine from Sulphur Creek, Colusa County. H. E. Kramm, analyst.

PROC. AMER. PHIL. SOC., XLIX, 196 W, PRINTED SEPTEMBER 9, 1910.

III. Serpentine from Oak Hill. Partial analysis by U. S. G. S.
IV. Serpentine from Presidio, San Francisco. J. D. Easter, analyst.

	V.	VI.	VII.	VIII.
SiO_2	39.64	39.98	40.50	41.52
Al_2O_3	1.30	1.12	.78	1.57
Fe_2O_3	——	13.19	4.01	3.50
FeO	7.76	1.05	2.04	1.07
MgO	37.13	30.49	37.43	36.84
CaO	——	.46	.39	.44
Na_2O	——	.28	.28	——
K_2O	——	.25	.16	——
H_2O	13.81	13.26	13.75	15.83
MnO	.12	——	.13	.29
Cr_2O_3	.29	trace	.41	——
TiO_2	——	tarce	——	——
NiO	.33	——	.11	——
P_2O_5	——	——	trace	——
Total	100.38	100.08	99.99	101.06

V. Black impure serpentine from near Borax Lake, Lake Co. Monograph XIII., U. S. G. S., 1888, p. 111. Analyst not stated.
VI. Serpentine from Mayacmas Range. H. E. Kramm, analyst.
VII. Serpentine from Mount Diablo. W. H. Melville, analyst.
VIII. Serpentine weathered interwoven with quartz and calcite from Mount Diablo. W. H. Melville, analyst.

TABLE OF ANALYSES.

Serpentines.

	IX.	X.
SiO_2	41.86	42.06
Al_2O_3	.69	2.72
Fe_2O_3	——	
FeO	4.15	2.88
MgO	38.63	39.53
H_2O	14.16	12.04
MnO	.20	——
Cr_2O_3	.24	——
NiO	trace	——
	99.93	99.23

IX. Pure serpentine from near Borax Lake, Lake County. Monograph XIII., U. S. G. S., 1888. Analyst not stated.
X. Serpentine from Angel Island. F. L. Ransome, analyst.

TABLE OF ANALYSES.

Pyroxenites.

	XI.	XII.	XIII.
SiO_2	42.76	53.25	56.98
Al_2O_3	5.71	2.80	1.73
Fe_2O_3	3.16	.69	4.04
FeO	3.30	5.93	4.18
MgO	27.11	19.91	27.40
CaO	10.03	16.22	3.26
Na_2O	2.24	.19	.59
K_2O	.49	trace	.35
H_2O	4.85	.29	2.04
MnO	——	.09	——
Cr_2O_3	.22	.54	.09
TiO_2	.17	——	none
NiO	——	.07	——
Total	100.04	99.98	100.66

XI. Pyroxenite-peridotite from Oak Hill near San Jose. H. E. Kramm, analyst.

XII. Fresh pyroxenite with some olivine from Mount Diablo. W. H. Melville, analyst.

XIII. Enstatite pyroxenite from near Coyote, Santa Clara Co. H. E. Kramm, analyst.

FIG. 1. Serpentine decomposing and giving rise to hydromagnesite. From Sulphur Creek. (Reduced ½ of diameter.)

FIG. 2. Bastite, pseudomorphous after pyroxenite. From the Knoxville area. (Reduced ½ of diameter.)

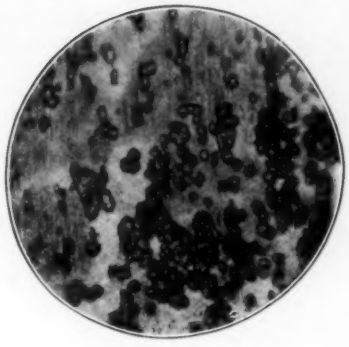


FIG. 3

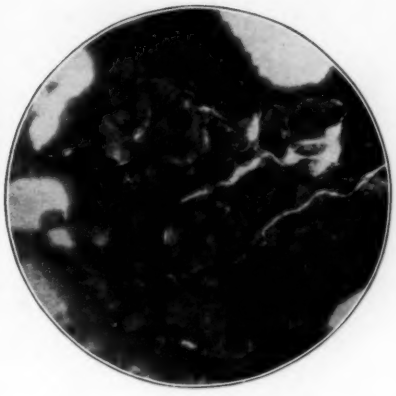


FIG. 4

FIG. 3. Grains of spinel in a bastite matrix. (Magnified 35 diameters.)
FIG. 4. Picotite with opaque chromite. (Magnified 35 diameters.)

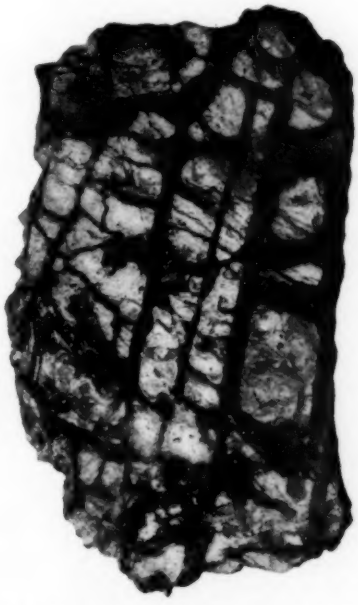


FIG. 5. Serpentine with veins of chrysotile stained by iron oxide. From the Oak Hill area, near San José. (Reduced ½ of diameter.)